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CONTENTS

VOLUME : 9

ISSUE : 1

PAGES : 3 – 141

- 1 Influence of Swine Wastes Rates on Selected Soil Physical Properties and Cultivation of Amaranthus in Awka, South East- Nigeria **3 – 13**
T.V. Nwosu
- 2 Soil Loss Estimation Using GIS and Remote Sensing Technique: A Case of Teaching and Research Farm, Kwara State University, Malete **14 – 27**
Khadijat Oyebisi Alabi, Isaac Afe Ade , Kabir Adebayo, Zainab Bolarinwa
- 3 Evaluation of Soils and Climatic Conditions Supporting Groundnut (Arachis hypogaea L.) Production in College of Agronomy Research Farms of Federal University of Agriculture Makurdi Benue State, Nigeria **28 – 41**
Emmanuel Amodu Igomu, Makama McGyotwowa Kyat, Simon Onyedikachi Odoemena
- 4 Role of Year-Round Plant Cover and Agro-Technical Measures on Arable Land for Improvement of Some Water-Physical Parameters of the Eutric Fluvisol **42 – 57**
Iliyana Gerasimova, Miladin Nazarkov
- 5 Influence of Land Use on Spatio-Temporal Variation in Soil Moisture in a Sahel Area of North East Nigeria. **58 – 68**
Ibraheem Alhassan, Suleiman Audu
- 6 Land Suitability Evaluation for Maize Production Among the Soils of Hyuku in Wukari, Taraba State, Nigeria **69 – 82**
Adashu Tanko Gani, Jacob Usman
- 7 Primary Nutrients Status of Three Vermicomposts Produced in a Nigerian Sahel Region **83 – 91**
Mahmud Sani, Alhassan Ibraheem, Sufiyanu Sani, Aliyu Abdulkadir, Ibrahim Hassan, Zara Musa, Musab Ibrahim
- 8 Pesticides and Soil Environment: An Age-Linked Concept. **92 – 112**
Suleiman Usman , James O. Jayeoba, Sani Mathew Amana
- 9 Modelling of Field Capacity from Basic Soil Properties on a Typical Alfisol **113 - 128**
K.O. Affinnih, N.B. Anwanane
- 10 Study of Basaltic Soils Along the Toposequence of Aya River in Ogoja, Cross River State, Nigeria **129 - 141**
P.E. Imadojemu, S.N. Obasi



Influence of Swine Wastes Rates on Selected Soil Physical Properties and Cultivation of Amaranthus in Awka, South East- Nigeria



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Abstract

Environmental threats most times occur due to indiscriminate disposal of swine wastes into the environment however effective disposal of these waste materials into the soil as an amendment for vegetable production remains a vital solution for the challenge. This research investigated different application rates of swine wastes on selected soil physical properties and cultivation of *Amaranthus* in Awka. The research was conducted at the Soil Science and Land Resources Management Research and Teaching Farm, Faculty of Agriculture, Nnamdi Azikiwe University, Awka- Nigeria. The field experiment was laid out in a Randomized Complete Block Design. Soil samples were taken from each plot with core samplers undisturbed and randomly and was taken to the laboratory for soil physical analysis prior to the application of treatment. The treatment used was swine wastes at rates of 0 kg/plot (zero application), 4.5 kg/plot, 9.0 kg/plot and 13.5 kg/plot. The test crop used was *Amaranthus hybridus*. The results obtained from the laboratory were subjected to statistical analysis and the treatment means were separated using Turkey test at 5% probability level. The results showed that the soils of the studied area was sandy loam. There was a significant difference in bulk density when the soil treated with 9.0 kg/plot was compared with 0 kg/plot (zero application) and it ranged from 1.75-1.97 g/cm³, the total porosity of soil in the studied area was significant when the soils treated with 9.0 kg/plot was compared with 0 kg/plot (zero application) and this ranged from 23.5 - 29.59 %, the moisture content of soil in the studied area was significantly different when soils treated with 9.0 kg/plot was compared with 0 kg/plot (zero application) and it ranged from 1.95- 3.22 %. The aggregate stability of soils in the area studied ranged from 0.37- 0.44 %, hydraulic conductivity of soils in the studied area was in the range of 0.01- 0.05 cm/hr. From this research, it was observed that 13.5 kg/plot of swine wastes applied improved the yield of *Amaranthus* when compared to other treatment rates.

Keywords: *Amaranthus*, application rates, slurry, soil, swine wastes

Introduction

The use of organic manures for the production of leafy vegetables has been reported to be effective (Iren et al., 2012) and the application of these organic materials as soil nutrients

provides growth-regulating substrates and improves the physical, chemical and microbial properties of the soil (Iren et al., 2015). Most tropical soils are highly susceptible to degradation under continuous cultivation however good quality soil is important for sustainable crop production especially under continuous cultivation. Amaranthus, also called African spinach, Bush green, Green leaf belongs to the family *Amaranthaceae*. They are the most commonly grown leafy vegetable of the lowland tropics in Asia and Africa. Amaranth leaves have wonderful chemical composition with mild spinach-like taste so it comes beneath an accurate leafy vegetable (Amicarelli and Camaggio, 2012). It may be eaten as raw in salad or by cooked along or with other vegetables especially with potato; due to its chemical composition it plays an important role in nutrition (Uusikua et al., 2010). It contains calcium, Magnesium, Carotene and Niacin, Vitamin A and C are also present in significant levels. The protein found in young plants of Amaranths can be important for people without access of meat or other sources of protein thus the need to sustain the cultivation of Amaranthus using adequate manure. Manure from swine production could be an asset to a pork producer and to agriculture in general if properly managed and utilized in a sustainable food production system and because swine manure contains essential plant nutrients, its use as a soil amendment for crop production is a practical method to solve the disposal problem. The composition and effectiveness of swine waste as a source of nutrients depends on several factors including the type of ratio fed, housing system and methods of manure collection, storage and handling. Soil is the dynamic link between the biosphere and the lithosphere and constitutes a practically non-renewable natural resources, with the key role for the environment and for the agriculture (Moraetis et al., 2016). Some factors such as altitude, parent rocks, vegetation and anthropogenic activities influences the physical properties of the soil like soil texture, bulk density and moisture content. Inappropriate disposal of swine wastes into the environment often times leads to environmental pollution which could pose a serious health challenge hence the need to channel these wastes into the soil as an amendment for vegetable production remains a solution to solving the disposal challenge.

Materials and Methods

Description of Experimental Site

The research was carried out at Soil Science and Land Resources Management Teaching and Research farm, Faculty of Agriculture, Nnamdi Azikiwe University, Awka-Nigeria. The research farm is located within latitude 6.244175⁰ N and 6.250008⁰ N and longitude 7.116615°E and 7.117172⁰ E, with an average annual rainfall of 2590.6 mm as per Nigeria meteorological Agency data for the year 2022; the rainfall distribution pattern is bimodal with early rain occurring between April and July and late rain between August and October. It has an average relative humidity range of 76 - 80 % and average maximum and minimum temperatures of 32.1 and 23.5°C respectively. The experimental site has a slight slope with a well-drained soil. The soils of the experimental area can be classified as Ultisols according to USDA soil classification system. Weeds such as *chromolena odorata*, *Aspillia africana*, *panicum maximum* and *cyperus spp* dominated the vegetation of the experimental site.

Experimental Design and Layout

The experiment was conducted in Randomized Completely Block Design (RCBD) with four treatments and three replications. The treatment used was swine wastes applied at the rates of 0kg/plot (Zero Application), 4.5 kg/plot, 9.0 kg/plot and 13.5kg/plot.

Field Operations and Soil Sample collection (pre-planting)

The experimental field size of 14.5 m x 15 m (217.5 Sq./m) was mapped out using a measuring tape, twine rope and pegs. Prior to land clearing, surface soil samples were collected from the experimental plot undisturbed from ten different points using core samplers for physical analysis while soil auger was used to collect soil samples at 20 different points at the depth of 0-20 cm after which it was bulked and mixed thoroughly from which a representative sample was collected. Land clearing was done using a cutlass; the debris were packed in between the furrows. Sixteen (16) plots of 3 m x 3 m (9 Sq./m) each was made using a hoe, the furrows spacing was 0.5 m x 1 m respectively while transplanting spacing used was 0.25m and 0.5m respectively for intra row and inter row respectively

Post planting

After harvest, soil samples for physical analysis were again collected accordingly; both samples collected prior to treatment application and after treatment/ harvest were respectively labelled and bagged for onward laboratory analysis.

Pre Nursery and Nursery Operation

The locally sourced seeds for the experiment were subjected to viability test of which 90 % germination was attained before planting in the nursery. A nursery bed was made very close to the experimental field for ease of transplant and to avoid transplanting shock of the Amaranthus seedlings. The swine wastes sourced from the Animal farm of the faculty of Agriculture was mixed in water to form slurry after which it was applied on the beds before transplanting. The swine wastes was directly applied on the experimental plots one week before transplanting with enough water applied daily to undergo a curing process. The Amaranthus seedlings transplanted had an average height of 0.32 m.

Plant Data Collection

Five middle stands from each plot were tagged and used as sample plants for data collection on the following agronomic properties.

- I. **Average plant height at 3 weeks after transplanting (3WAT):** The plant height was measured using a meter rule from soil level to the apex of the leaves at 3 weeks after transplanting.
- II. **Leaf area index:** The leaf area was measured using a meter rule, it was calculated according to the procedure of Samkeliso et al., 2020
- III. **Fresh shoot weight:** Fresh shoot was harvested and weighed using weighing balance
- IV. **Dry shoot weight:** The fresh shoot was subjected to drying in the oven at a temperature of 105°C for 72 hours until a constant weight was achieved it was weighed again.
- V. **Number of nodes after first and second cut:** The nodes were counted after first and second cut

Laboratory analysis

Particle size Distribution: The hydrometer method as described by Gee and Or 2002 was used to determine the particle size distribution of the samples while the soil textures were determined using the USDA Textural triangle. The bulk density was determined by core method as described by Grossman and Reinsch (2002). Saturated Hydraulic conductivity (k_{sat}) was determined by method of Young (2001). Soil Aggregate stability was determined using wet sieving method of Kemper and Rosenau (1986). Soil Total Porosity was calculated from the bulk density as shown in this equation:

$$\text{Total porosity (\%)} = \frac{1 - \text{Bd}}{\text{pd}} \times 100 \quad \dots\dots\dots (1)$$

Where Bd=Bulk density

Pd=particle density (2.65g/ cm³)

Moisture content of the soil was determined by oven drying at a temperature of 105⁰C and percentage of moisture in soil calculated mathematically as follows:

$$GMC = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad \text{Where } W_1 = \text{Weight of the can, } W_2 = \text{Weight of wet sample + can, } W_3 = \text{Weight of oven dried sample + can}$$

Statistical analysis

Data collected were subjected to Welch's one way Analysis of variance (ANOVA) using SAS Statistical package version 9.4. Separation of treatment means was done using turkey test.

Results and Discussion

Pre-Treatment Soil Properties

The results of soil physical properties of the experimental site before the application of treatment are shown in table 1. From the results obtained, the study area had a mean sand, silt and clay contents of 704 g/kg, 216 g/kg and 80 g/kg respectively, having a textural class of sandy loam. The soils of the study area had a mean bulk density of 1.54 g/ cm³, total porosity of 41.77 %, soil moisture content of 9.67 %, hydraulic conductivity of 0.18 cm/hr and aggregate stability of 0.45%.

Table 1. Soil Pretreatment properties of the Experimental site.

Soil Parameters	Values
Sand (g/kg)	704
Silt (g/kg)	216
Clay (g/kg)	80
Textural class	Sandy loam
Bulk density (g/ cm ³)	1.54
Porosity (%)	41.77
Aggregate stability (%)	0.45
Moisture content (%)	9.67
Hydraulic conductivity (cm/hr)	0.18

Nutrient Properties of swine wastes

Prior to the treatment application (Swine wastes), it was subjected to laboratory analysis to determine the constituent elements and the results are shown in table 2.

Table. 2. *Nutrient composition of swine waste*

Swine waste properties	values
Organic matter	3.71 %
Total Nitrogen	3.21 %
Available Phosphorus	1.68 mg/kg

Post-Treatment Soil Properties

From the results obtained as shown in table 3, the plot with zero application had an average sand, silt and clay contents of 729 g/kg, 206 g/kg and 65 g/kg respectively, the plot treated with 4.5 kg/plot of swine waste had an average sand, silt and clay contents of 719 g/kg, 201 g/kg and 81 g/kg respectively, the plot treated with 9.0 kg/plot of swine waste had an average sand, silt and clay contents of 719 g/kg, 200 g/kg and 81 g/kg respectively while the plot that was treated with 13.5 kg/plot of swine waste had an average sand, silt and clay contents of 749 g/kg, 175 g/kg and 95 g/kg respectively. The results showed that there was no treatment effect on the texture of the soil; however the sandiness of the studied area could be attributed to the nature of the parent material from which the soils were derived. Soils of the experimental area belongs to textural class of sandy loam. Higher sand contents obtained in soils of the studied area could suggest low cation exchange capacity, leaching of nutrients and can encourage soil erodibility on exposure to high rainfall (Nwosu et al., 2023). The plot with zero treatment (control) had a mean soil bulk density of 1.97 g/ cm^3 , the plot with treatment applied at the rate of 4.5 kg/plot and 9.0 kg/plot had mean soil bulk densities of 1.86 g/ cm^3 and 1.75 g/ cm^3 respectively while the plot with the treatment applied at the rate of 13.5 kg/ ha had a mean soil bulk density of 1.89 g/ cm^3 . There was a significant difference in the soil bulk densities when the plot with zero treatment was compared with the plot of 9.0 kg of swine wastes. Bulk density reduces with the application of animal manures; this is because the organic matter has a lower particle density than the mineral particles and its increase results in reduction of the soil particulate density as a whole. Again, increase in soil organic matter increases the degree of soil aggregation, increasing the volume of pores. Soil bulk density as observed in this study was slightly higher than normal and could be attributed to soil compaction owing to machinery compression in the course of road construction around the experimental site. According to Celik et al., 2004; Barzegar et al., 2002, Bulluck et al., 2002 reduction in soil bulk density occurs both with the application of manures alone and in association with mineral fertilizers (Hati et al., 2008; Bandyopadhyay et al., 2010). The plot with zero treatment (control) and 4.5 kg/plot of swine wastes had an average mean total porosities of 25.72 % and 28.91 % respectively, while the plots treated with 9.0 kg/plot and 13.5 kg/plot of swine wastes had a mean total porosities of 23.59 % and 29.59 % respectively. The plot with 13.5 kg/plot had the highest total porosity of 29.79 % while the plot treated

with 9.0kg/plot of swine wastes had the least total porosity of 23.59 %. The results obtained in several studies with application of manure presented divergent results regarding their effects on the total porosity and the classes of pores. Increase in total porosity as often observed is due to the increase of pores with larger diameter ie macropores which is associated with better soil structure (Celik *et al.*, 2004; Rós *et al.*, 2013). Marinari *et al.*, (2000) observed that the increase of macropores in the soil treated with organic fertilizer was mainly due to an increase in the elongated pores which are considered very important for both soil-water plant relationships and maintenance of good soil structure. For aggregate stability; the results showed that the plot with zero treatment had 0.3 %, the plot with 4.5 kg/plot had a mean aggregate stability of 0.44 % while the plot treated at the rates of 9.0 kg/plot and 13.5 kg/plot had a mean aggregate stability of 0.40 % and 0.37 % respectively. The plot with 4.5 kg/plot of swine wastes had the highest aggregate stability with a mean value of 0.44 % while the control and 13.5 kg/plot had 0.37 % mean values respectively being the least. Soil aggregate stability is one of the properties most influenced by increase in manure application however swine wastes application at the rate of 13.5 kg/plot did not increase the aggregate stability and could be as a result of the short period of the experiment. According to Kay *et al.*, (1999) , a level of soil organic carbon of 2.0 to 2.5% is considered necessary to maintain good aggregate stability and aggregate stability is considered to deteriorate rapidly when soil organic carbon falls below 1.2% to 1.5%. Again, the results obtained showed that the plot with zero treatment (control) had a mean hydraulic conductivity of 0.02 cm/hr, the plot with swine waste 4.5 kg/plot had a mean hydraulic conductivity of 0.01 cm/hr, the plot with 9.0 kg/plot had a mean hydraulic conductivity of 0.03 cm/hr while the plot with 13.5 kg/plot had a mean hydraulic conductivity of 0.05 cm/hr. The plot with 13.5 kg/plot had the highest mean value of 0.05 cm/hr while the plot with 4.5 kg/plot had the least mean value of 0.01 cm/hr.

Table. 3. *Influence of application rates of swine wastes on selected Soil Physical Properties*

TRTs	BD (g/cm ³)	TP (%)	MC (%)	Aggregate Stability	Ksat (cm/hr)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Textural class
0 kg/plot	1.97 ^a	25.72 ^b	1.95 ^c	0.37 ^a	0.02 ^a	729	206	65	SL
4.5 kg/plot	1.86 ^{ab}	28.91 ^{ab}	2.26 ^{bc}	0.44 ^a	0.01 ^a	719	201	81	SL
9.0 kg/plot	1.75 ^b	23.59 ^a	3.22 ^a	0.40 ^a	0.03 ^a	719	200	81	SL
13.5 kg/plot	1.89 ^{ab}	29.59 ^{ab}	2.97 ^{ab}	0.37 ^a	0.05 ^{ab}	749	175	76	SL

Note: TRTs- Treatments BD –Bulk density TP - Total porosity MC-moisture content
Ksat – saturated hydraulic Conductivity

There was a significant difference in soil hydraulic conductivity when plot treated with 13.5kg of swine wastes was compared with the control. Some researchers have reported seepage reduction due to sealing of soils by animal manure and by other organic liquids which

was observed in this study. In their submission, organic manure is known to improve soil physical properties (Andersodu et al., 2013, Aluko and Oyeleke, (2005).

Agronomic properties

Some agronomic properties such as plant height, leaf area index and number of leaves, Fresh shoot weight, dry shoot weight, number of nodes at first and second cuts were taken 3weeks after transplanting to determine the influence of swine wastes application rates on the *Amaranthus* plant.

Plant Height

From the results obtained, the plots with 0kg, 4.5 kg/plot, 9.0 kg/plot, and 13.5 kg/plot rates of swine waste application had a mean plant height of 37.25 cm, 39.65 cm, 44.90 cm, and 49.95 cm respectively. Highest height was observed in the plot treated with 13.5 kg/plot of swine waste while the lowest height was observed in the plot with zero treatment. Giacomini and Aita (2008) revealed that animal waste such as deep litter and liquid pig slurry applied as a source of N for corn increased the availability of this nutrient in the soil throughout the crop cycle compared to the control treatment.

Leaf area index and number of leaves

The plots with zero treatment had a mean leaf area index and number of leaves of 37.60 cm and 43.15 cm respectively, the plot treated with 4.5 kg/plot of swine waste had a mean leaf area index of 46.50 cm and 60.90 cm respectively, the plot treated with 9.0 kg/plot of swine waste had a mean leaf area index of 43.47 cm and 73.00 cm respectively while the plot treated with 13.5 kg/plot of swine waste had a mean leaf area index of 70.80 cm and 73.90 cm respectively. There was a significant difference at 5% probability level in the leaf area index when the plots with 0kg/plot, 4.5kg/plot, 9.0kg/plot swine waste application were compared with 13.5kg/plot swine waste application. Leaves are the main source of food synthesized for the plant and thus their absence affects plant growth and development thus Leaf area is recognized as a crucial growth index determining the capacity of plants to trap solar energy for photosynthesis and has marked effect on growth and yield of plant (Mathowa et al., 2014)

Table. 4. *Influence of application rates of swine wastes on some agronomic properties*

TRTs	Plant Height	Leaf area index	Number of leaves	FSW (kg)	DSW (kg)	NODES (1ST CUT)	NODES (2ND CUT)
0kg/plot	37.25 ^a	37.60 ^a	43.15 ^a	0.51 ^a	0.15 ^a	13.85 ^a	4.80 ^a
4.5kg/plot	39.65 ^{ab}	46.50 ^a	60.90 ^{ab}	0.32 ^a	0.15 ^{ab}	14.75 ^b	5.85 ^a
9.0kg/plot	44.90 ^b	43.40 ^a	73.00 ^b	0.47 ^a	0.12 ^b	14.50 ^b	4.75 ^b
13.5kg/plot	49.95 ^{bc}	70.80 ^b	73.90 ^b	0.51 ^a	0.17 ^c	13.10 ^b	4.75 ^b

N/B: FSW =fresh shoot weight, DSW=Dry shoot weight

Fresh shoot weight, Dry shoot weight, Number of nodes at first and second cut.

The plot treated with 13.5 kg/plot of swine waste gave the highest dry shoot weight of 0.17kg, while the plot treated with 9.0 kg/plot of swine waste had the lowest weight of 0.12kg. Nodes were more at the first cut than in the second cut at various application rates however there was a significant difference in the nodes at the first cut when plots with 4.5 kg/plot, 9.0 kg/plot and 13.5 kg/plot were compared with zero application. Generally, it was observed that plant height, leaf area index, number of leaves, fresh shoot and dry shoot weight increased with an increase in treatment application rates. This could be attributed to high content of Total N, P and K in the pig manure. Adebayo et al (2011) found out that organic amendment increased both vegetative and dry matter yield of *Moringer oliefera*.

Conclusion

The application of swine wastes at different rates had an appreciable impact on some soil physical properties such as the soil bulk density, total porosity and moisture content. The research showed that the higher the rate of swine wastes application for cultivation of *Amaranthus* the better the growth and yield which was evidenced in the plant height, leaf area index, number of leaves as well as fresh and dry shoot weights measured.

Recommendation

Farmers growing annual crops with short growth cycle such as *Amaranthus* should use swine wastes at rate of 9kg/plot and above to obtain relative higher yields.

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Soil Loss Estimation Using GIS and Remote Sensing Technique: A Case of Teaching and Research Farm, Kwara State University, Malete



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Abstract

Due to ongoing cultivation, the Teaching and Research Farm of Kwara State University in Malete has seen quick and accelerated erosion. Run-off-related soil loss is a significant and persistent ecological problem in the study area. Information on soil loss is essential for promoting agricultural production and natural resource management. The average annual soil loss was calculated and mapped in this study using remote sensing and GIS. The soil loss was computed using the Revised Universal Soil Loss (RUSLE) Model. Using a topographic map at a scale of 1:50,000, an aster digital elevation model (DEM) with a spatial resolution of 20 m, a digital soil map at a scale of 1: 250,000, rainfall data spanning 39 years (1981-2020), and other data, RUSLE's soil loss variables were calculated. The RUSLE parameters were investigated and incorporated using a raster calculator in the geo-processing tools in the arc-GIS 10.1 environment to estimate and map the annual soil loss of the research region. The results show that the annual soil loss in the study region ranged from 48.553 to 1,476.606 t ha⁻¹ year⁻¹, cover around 100 ha of land. Most of the soil erosion affected areas are spatially situated in block 2B and 3A part of the farm. These are areas where low Ferric Luvisols and high Ferric Luvisols with higher soil erodibility character (21-33) values are dominant. Therefore, it was found that the main causes of soil erosion were slope gradient and length, followed by soil erodibility parameters. The study therefore recommended using sustainable soil and water conservation methods to address the problem of soil erosion in the study area.

Keywords: Soil Loss, Soil erodibility, Slope gradient, Arc-GIS, Ferric Luvisols, RUSLE

Introduction

During the process of soil erosion, topsoil on the soil surface is lifted off the ground by water or wind and transferred to other surfaces. It is regarded as the biggest environmental problem the world is currently facing, second only to population growth. According to Pimentel et al. (2009), who provided examples of the United States losing soil at a rate of 10-

40 times faster than the average replacement rate and China and India losing soil at a rate of 30–40 times faster, the majority of soil from farmlands is washed away about 10–40 times faster than it is being replaced. The trend of soil erosion increased during the 20th century. Soil erosion has reduced crop yield by 17%, the majority of which has happened since the end of World War II. It has been established in the literature that eroding soils emit harmful farm chemicals into streams, rivers, surface waters, and groundwater resources (N_2O), as well as atmospheric pollutants like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide. Thirty percent of the world's arable land has become unusable during the past forty years due to erosion.

It is still difficult to find a model that can estimate soil loss from all sources of erosion from a particular site. One of the parametric models utilized to calculate soil erosion is the Universal Soil Loss Equation. Studies using the Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), Limberg Soil Erosion Model (LISEM), and Soil Loss Estimation Model for Southern Africa (SLEMSA) have shown that eroded soils carry harmful farm chemicals into streams and rivers and contaminate surface and groundwater resources. The USLE (Wischmeier and Smith 1978) was previously considered to be the best equation for calculating soil loss due to its simplicity and resilience. However, it has been demonstrated that when applied to areas of the world other than the United States of America, it is insufficient due to variations in the soil types and rainfall patterns found in these areas. In recent years, RUSLE has been used in several research across the globe (Adediji et al., 2010; Nangia et al., 2010; Sajaul et al., 2012).

This demonstrates the method's adaptability to locations with a range of climatic factors and soil types. The RUSLE erosion model, which was developed to calculate the average soil loss over the long term due to runoff from a certain field slope, would compute the average soil loss with the proper selection of its factor values. The soil loss predicted by RUSLE is brought on by sheet and rill erosion. Sheet erosion, the initial stage of water erosion, is the process by which rainfall and runoff remove a layer of soil from the surface of the land. Contrarily, rills are often located on agricultural land and are associated with agricultural activity.

There isn't much information available at the KWASU Teaching and Research Farm about soil loss or how likely soil erosion is to occur, and neither GIS nor remote sensing methods have been used to aid. Therefore, this work aims to estimate and map the geographical pattern of annual soil loss rate by water using the Revised Universal Soil Loss Equation (RUSLE) simulated using GIS and Remote sensing techniques.

Materials and Methods

The Teaching and Research Farm at Kwara State University in Malete (KWASU T&R), which is located in the Moro Local Government Area of Kwara State, served as the study's experimental location (Figure 1).

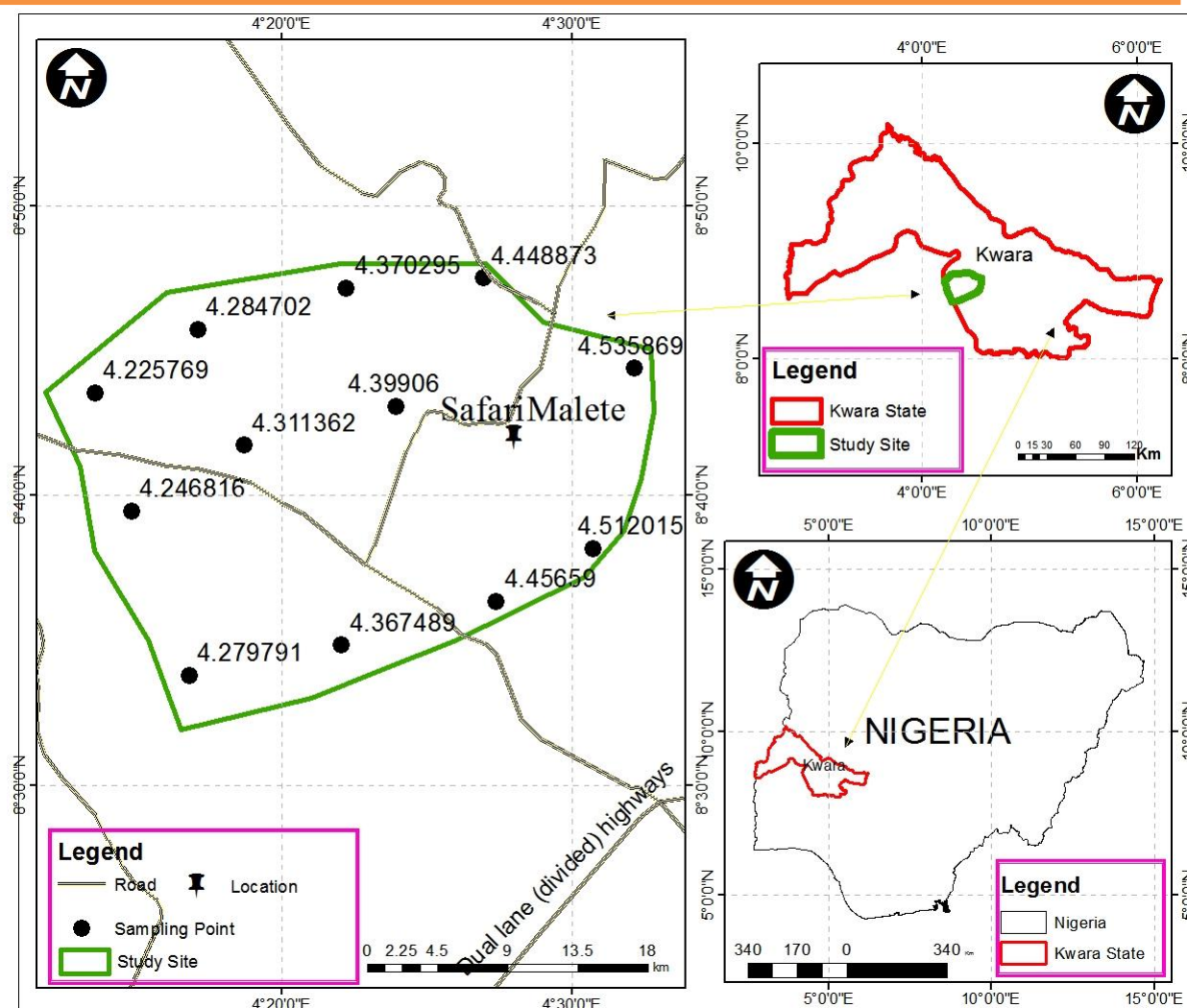


Figure 1. Location Map of the study area. (Source - Alabi et al., 2017.)

It is located eight kilometers north of the agricultural buildings and covers about 100 hectares. The farm is located 360 meters above sea level, between Latitude $08^{\circ}71'N$ and Longitude $04^{\circ}44'E$, and the terrain is fairly gentle. It is situated in Nigeria's Southern Guinea Savannah ecological zone. It consists of a farm center and a space for teaching and research by the departments of crop production, agricultural economics, and extension services. It also includes a section for animal production, which includes fisheries and aquaculture, small and large ruminant, poultry, and rabbitry. It is characterized by distinctive wet and dry seasons with a mean annual rainfall of about 1150 mm, with a double maximal pattern between April and October. The dry season starts in November and lasts until March, whereas the wet season starts in April and concludes towards the end of October. The average yearly temperature ranges from 25 to $28.9^{\circ}C$ degrees. The land area is a part of the Nigerian basement complex's South-Western zone of basement reactivation. The area is predominantly used for the cultivation of arable crops such as maize, groundnut and cowpea, perennial trees such as cashew and mango. The site also contains a variety of grasses, including spear grass, elephant grass, and Guinea Gamba grass, as well as woody species including the baobab (*Adansonia digitata*), neem tree (*Azadirachta indica*), and acacia (*acacia species*).

For this investigation, both primary and secondary data sources were used. Primary data were collected using GPS devices through field surveys, ground truth authentication, and observation. This gives precise information about what is happening in the study area. The six blocks that made up the farm were Crop Museum, Block 2A, Block 2B, Block 3A, Block 4, and Operation Feed Yourself field. To produce primary data pertaining to ground truth for the purpose of training the image utilizing supervised image classification and producing thematic land use and land cover maps, intensive field observations using GPS were conducted in each block of the farm. For each key land-use/cover category, ground control points (GCPs) were also acquired in order to validate accuracy. Additional data includes the soil map (1:250,000), the slope length-steepness (LS) factor, a 2019 Thematic Mapper (TM) multi-spectral image with a spatial resolution of 30 m (land-use/land-cover map), and 39 years (1981-2020) of rainfall records from the Lower Niger Basin. These data sources were all downloaded from the Global Land-cover Facility (www.landcover.org). The Google Earth image was also made and digitized. Each layer of the RUSLE parameters was discretized and structured to the DEM's (20×20) cell size in order to obtain a fine grid-based soil loss result and to derive a precise slope length-steepness factor value. Digital technology and the Google Earth image were used to produce a map of the research area's waterbodies. Published and unpublished resources, such as research papers, census reports, and journal articles that were gathered from various sources, as well as the aforementioned secondary data, were also used.

The Revised Universal Soil Loss Equation (RUSLE) was used to calculate the mean yearly soil loss that took place in the Teaching and Research Farm using the enhanced LS factor estimation approach. The empirical formulation of the Revised Universal Soil Loss Equation (RUSLE) is:

$$A \text{ (M t/ ha}^{-1} \text{ yr}^{-1}) = R * K * LS * C * P \dots\dots\dots \text{Equation 1}$$

where A is the mean annual soil loss (M t/ha⁻¹ yr⁻¹); R is the rainfall erosivity factor (MJ mm h⁻¹ ha⁻¹ year⁻¹); K is the soil erodibility factor (M t/ha⁻¹ MJ⁻¹ mm⁻¹); LS is the slope length–steepness factor (dimensionless); C is the cover and management factor (dimensionless); and P is the erosion support practice or land management factor (dimensionless and ranges from zero to one). The RUSLE model was simulated by GIS and Remote sensing techniques. While the raster calculator geo-processing tool, the R-value of each grid cell or block was determined from this continuous rainfall data.

$$R(eq) = -823.8 + 5.21Pr \dots\dots\dots \text{Equation 2}$$

Where;

Req= Equivalent R factor for unique climatic condition\

Pr= annual precipitation, mm

Results and Discussion

Assessment of the rate of soil loss

In this work, the Revised Universal Soil Loss Equation (RUSLE) model was used to calculate the mean annual soil loss rate ($t/ha^{-1} yr^{-1}$) cell by cell. The Teaching and Research Farm in Malete (Figure 1) also discovered and documented soil erosion danger zones. The following are a few of the raster maps that were made and discussed for each RUSLE parameter:

Rainfall erosivity (R) factor

According to Equation (2), the erosivity factor is estimated to be between 87.391 and 91.086 $MJ mm h^{-1} ha^{-1} yr^{-1}$. The rainfall erosivity factor, which also considers the amount and rate of runoff that is most likely to be associated with precipitation events, measures the influence of rainfall. The Lower Niger Basin Meteorological Station in Ilorin, Kwara State provided the mean annual rainfall for the research area, which was interpolated in the ArcGIS 10.1 environment using the inverse distance weighted approach (Table 1) to create unbroken rainfall data for each grid cell.

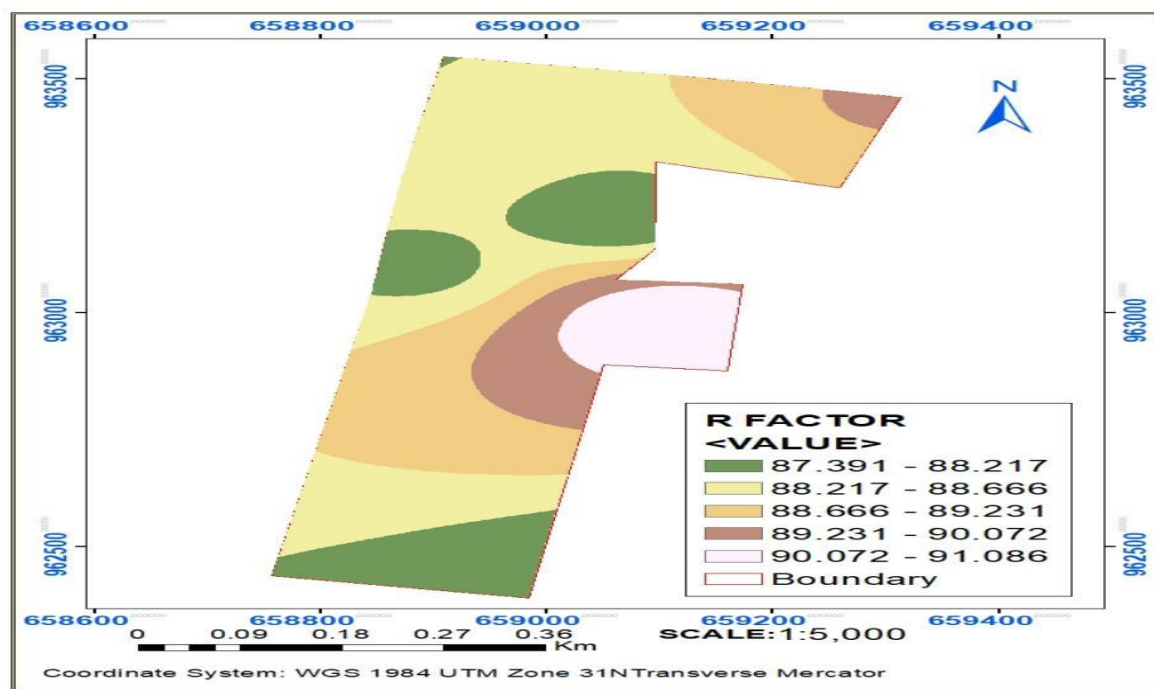


Figure 2. Rainfall Erosivity (R) factor

Soil erodibility (K) factor

The natural resistance of soil particles to the detaching and transporting power of precipitation is a sign of soil erodibility (Wischmeier & Smith, 1978). This component assesses a soil type's cohesiveness and resistance to dislodging and transport caused by the force of overland flow shear pressures and raindrop impacts. For a particular soil type, the K-factor is empirically computed to represent the physical and chemical properties of the soil that affect its erodibility potential (Figure 3). The Teaching and Research Farm's erodibility K-factor ranges from 10 to 33 $\text{mt/ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ (Table 1). The highest erodibility factor values were reported by Ozcan et al. (2008) using USLE and GIS, which is consistent with the findings of our work. Koulin et al. reported similar findings in the Chania watershed in Greece in 2009.

Table 1. *Estimated K Value for Each Block*

Block	Soil Name/Class	Estimated K value (metric tons $\text{ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$)
Crop museum	High ferric Luvisols	21
2A	High to Medium ferric Luvisols	10 - 21
2B	High to Medium ferric Luvisols	10- 21
3A	Low ferric Luvisols	33
4	Low ferric Luvisols	33
Operation feed Yourself field	Medium ferric Luvisols	10

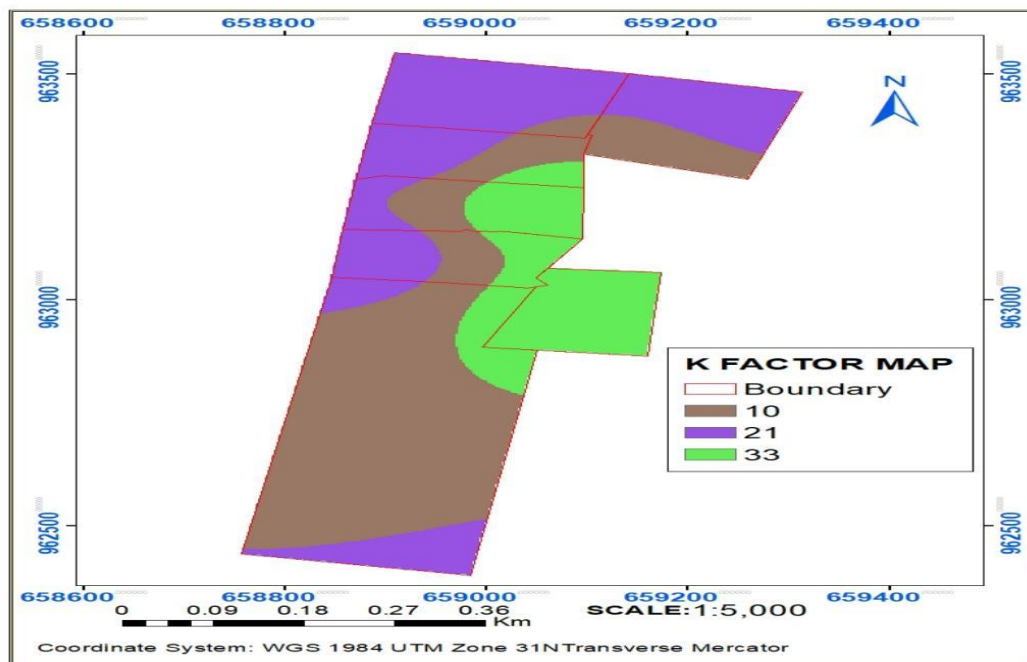


Figure 3. *Soil Erodibility (K) factor*

Slope length and steepness (LS) factor

Using Simms et al., (2003), the topographic component of RUSLE was calculated. Slope length was replaced for the upslope contributing area in order to account for the flow convergence and divergence in a three-dimensional complicated terrain situation. The (LS) factor, under otherwise identical conditions, is the ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9% slope (Wischmeier & Smith, 1978). In this case, the slope-length (L sub-factor) refers to the distance between the beginning and end of the inter-rill process. The culmination occurs when the flow concentrates into a rill or other man-made channel, such as a terrace or diversion, or when the slope begins to drop and the subsequent depositional process begins (Wischmeier & Smith, 1978; Renard *et al.*, 1996).

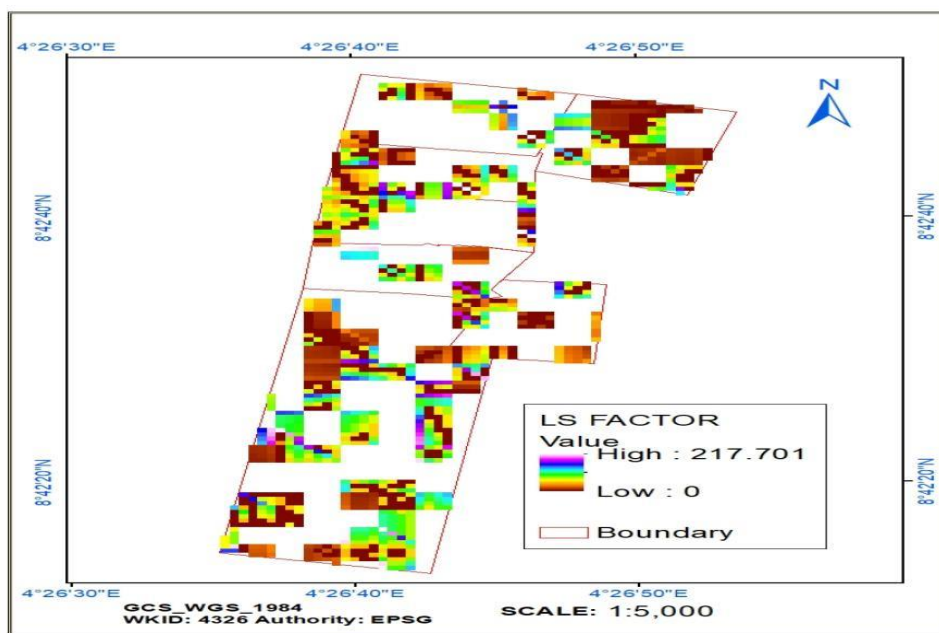


Figure 4. Slope Length and Steepness (LS) Factor

Slope determination utilizing a geographic information system (GIS) has benefits for a wide range of environmental models because slope properties are typically needed as input for landslides, land planning and construction, and other environmental models (Dunn & Hickey, 1998). the length of the slope-drawbacks. When applying the Universal Soil Loss Equation, the cumulative uphill length from each cell can be used to overcome the limitations of slope-length computation by taking into consideration convergent flow pathways and depositional areas (Hickey, 2000). The supposed transport capacity of the flow is measured by the LS factor in the RUSLE (Moore & Wilson, 1992). Without accounting for the intricate three-dimensional geometry of the landscape. The supposed transport capacity of the flow is measured by the LS factor in the RUSLE (Moore & Wilson, 1992). The slope-length calculation approach employed in USLE and RUSLE was based on the notion that the longer the slope, the greater the soil loss (Robert & Hilborn, 2000). This was done without taking into account the complicated three-dimensional geometry of the terrain (Figure 4). The results of slope length indicate that the prolonged areas of steep slopes are susceptible to severe erosion. In the Turkish Kazan watershed, Erdogan et al. (2007) used USLE and GIS models

and reported similar, reliable results. Crop Museum and Operation Feed Yourself Field's topography favoured less erosion in general. This suggests that the land is seriously endangered, which affects its output. High correlation between steep slopes and poor surface cover within the farm was also reported by Kouli, 2009 in the Crete watershed.

Support practice (P) factor.

The erosion control practice factor (P-factor) is the ratio of soil loss caused by a certain support practice to losses comparable to those caused by upslope and downslope agriculture (Wischmeier & Smith, 1978). The generated P-factor map (Figure 5) is not used to comprehend the conservation practices being applied in the research region. The preventative measures that affect drainage patterns, runoff concentration, and runoff velocity and minimize the erosive power of rainfall and runoff are considered in this component. The classed land-use/land-cover and slope thematic map format was converted to vector format and the corresponding p values were added to each combination of land-use/land-cover and slope classes in order to build a raster map of the P factor.

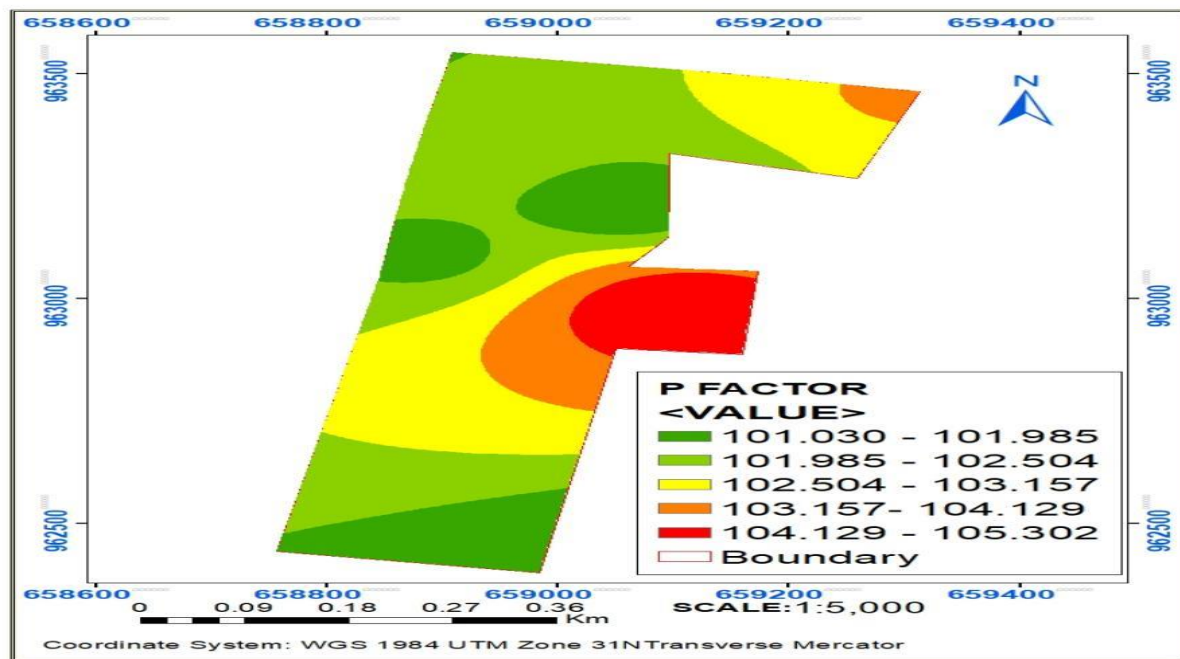


Figure 5. Support Practice (P) Factor

Cover and management (C) factor.

The cover and management (C) factor is defined as the ratio of soil loss from land with a specific vegetation to the corresponding soil loss from a continuous fallow (Wischmeier & Smith, 1978; Morgan, 2005). It is the component that can be changed the most and is typically taken into consideration when developing a conservation strategy. The major method for gathering data on the dominant categories of land use and land cover in the study area was unsupervised categorization. On the basis of this data, supervised classification supported by GCPs was used to produce themed land-cover maps. The thematic land-use and land-cover raster map of Teaching and Research Farm, Malete was then

transformed to vector format in order to assign the proper cover and management factor value derived from various studies. The result was a C-factor raster map, as shown in Figure 6.

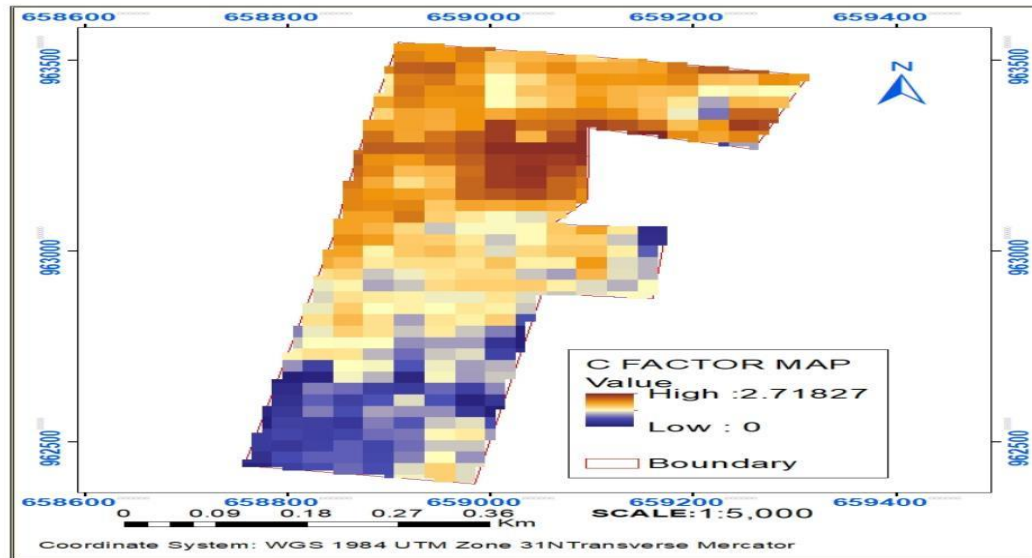


Figure 6. Cover and Management(c) factor Map

The primary land-uses/covers of the Teaching and Research Farm that were identified using supervised image classification were water bodies and cultivated land. Maize, cowpeas, groundnuts, melon, guinea corn, and other vegetation dominated the area. Crop covers with the greatest C-factor values (0.1). This ensures that annual crops like millet and maize do not mitigate the direct effects of rainfall on soil resources, unlike forest land. Thus, the final map that shows the anticipated annual soil loss of the Teaching and Research farm was produced by superimposing the aforementioned five parameters (K, R, LS, C, and P) using Eq. (1), raster calculator geo-processing tools, and the ArcGIS10.1 environment (Figure 7).

The cell sizes for the DEM were resampled (20×20 m), and each layer was organized in a grid style. The soil erosion map of the study area was divided into six classes for the purpose of management prioritization, as shown in Table 1 and Figure 7. The level of soil loss risk in the research region has also been classified and the potential amount of soil loss has been predicted using the statistical approach. As shown in Figure 7, the annual soil loss of Teaching and Research farm extends from 0 to 1,476.606 M t/ ha⁻¹ yr⁻¹ with a mean annual soil loss rate of 47.4 Mt/ ha⁻¹ yr⁻¹. The total annual soil loss in the Teaching and Research farm is 1476.606 t; which covers about 100 ha of land. This lost is at a rate much greater than the tolerable soil loss rate (Table 2).

Table 2. Annual Soil loss range, Block coverage and severity class

Annual soil loss (tone)	Soil erosion risk class	Block coverage	Percent of total soil loss
0-48.553	Low	Crop museum	2.02
48.553-140.031	Moderate	Operation feed yourself field	5.83
140.031- 280.367	High	2A and 2B	11.68
280.367- 455.398	Very high	4	18.97
455.398-1476.606	Severe	3A	61.5

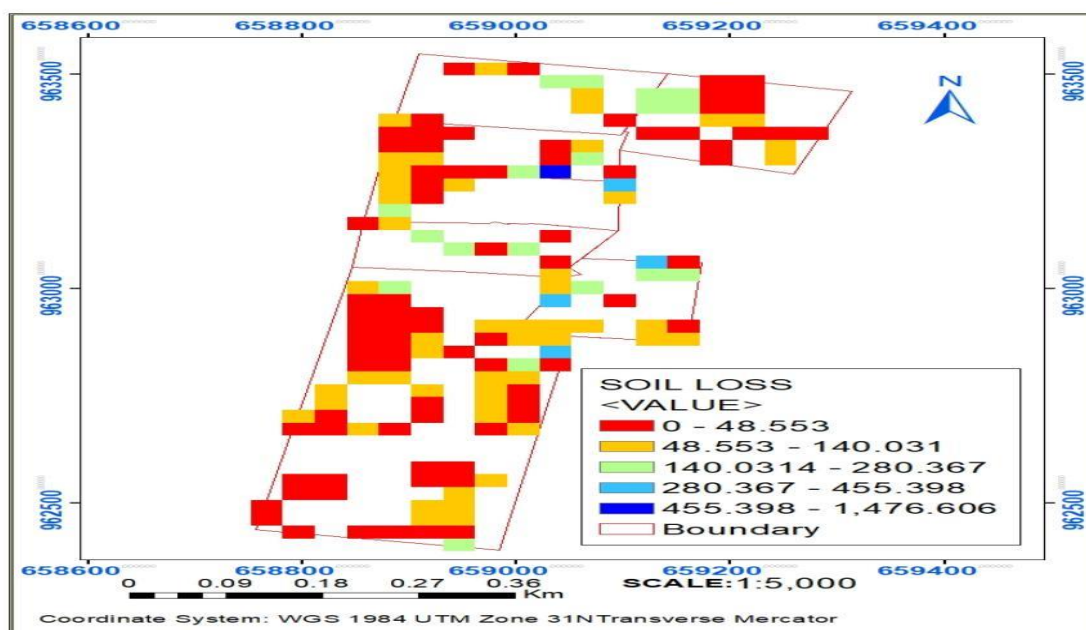


Figure 7. Soil loss rate Map

Tolerable soil loss rate (FAO, 1984) is defined as the highest allowable soil loss rate that can support economic growth and high levels of production. Since the majority of the primary soil types on the Teaching and Research Farms in Malete have soil depths between 0 and 150 meters, the FAO's (1994) tolerable soil loss rate for deep and very deep soil depths is 4.2 to 7.2 t/ ha⁻¹ year⁻¹. This suggests that the land is seriously endangered, which affects its output. This implies that the land is gravely in jeopardy, which has an impact on its productivity. Additionally, the system that keeps life from dying could deteriorate until it reaches an irreversible condition. The Teaching and Research farm's yearly soil loss ranges from 0 to 1,476.606 Mt/ ha⁻¹ yr⁻¹, with a mean rate of 47.4 metric t/ ha⁻¹ year⁻¹. In the Teaching and Research farm, the total yearly soil loss is 1476.606 t, which occupies a space of around 100 ha. Compared to the permitted rate of soil loss, this loss is occurring far more quickly than the allowable rate of soil loss (Table 2). Tolerable soil loss rate (FAO, 1984) is defined as the highest allowable soil loss rate that can support economic growth and high levels of production. Since, most of the major soil types of Teaching and Research farm, Malete have soil depth ranges from 0 – 150 m deep (Alabi et al., 2017), the soil loss rate in the study area is far beyond FAO (1994) tolerable soil loss rate of 4.2–7.2 t/ ha⁻¹ yr⁻¹ for deep and very deep soil depth respectively. Kumar et al., (2022) reported an average annual soil loss of 1.60 t. ha⁻¹. yr⁻¹ in the lower Chambal basin in Madhya Pradesh using RUSLE model. Adhikary et al., (2014), Suryawanshi et al., (2023) reported similar results by comparing USLE and RUSLE models in Central Indian Chambal River Basin.

Conclusion

Information about the quantitative and spatial extent of soil loss derived by modeling of RUSLE parameters Malete ensures the management of spatially variable data and inaccessible location where ground-based observation is challenging by using GIS and Remote sensing techniques in Teaching and Research farm. As a result, the method can be used in other areas of the community for the evaluation and identification of regions that are

prone to erosion, the setting of conservation priorities, and the evaluation of the effectiveness of different land management strategies.

The results of this study take into account the erosion risk map and the spatially distributed soil loss rate of Kwara State University's Teaching and Research Farm in Malete. The annual soil loss at Malete's Teaching and Research farm ranges from 0 to 1476.606 metric tons. Slope-length and gradient (LS) factor was shown to be the most important RUSLE parameter by the results as well. According to the soil erodibility (K) factor, the potential soil loss is therefore frequently greater along the steeper slope and in areas with less vegetation cover.

The areas used for Operation Feed Yourself and Crop Museum Block have been discovered to be the least prone to soil erosion. Therefore, in order to reduce soil erosion, the research area's conservation and management measures are strongly suggested. Areas where significant soil loss was detected should be given careful thought. An appropriate land use plan and an Environmental Impact Assessment (EIA) are required for the locations that have been made accessible on the University's Teaching and Research farm. For immediate soil protection efforts in their agricultural regions, local residents and researchers in the area should embrace various soil protection approaches, such as mulching, contour plowing, repeated cropping, and other indigenous soil conservation strategies. Additionally, using enough vegetative cover and adding organic manure should be considered.

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Evaluation of Soils and Climatic Conditions Supporting Groundnut (*Arachis hypogaea* L.) Production in College of Agronomy Research Farms of Federal University of Agriculture Makurdi Benue State, Nigeria



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Abstract

Makurdi is in a strategic position in the agricultural map of Nigeria, producing a wide range of both annual and perennial crops such as yam, maize, rice, sorghum, soybean, cowpea, citrus, mangoes, and a variety of vegetables. One of the factors responsible for this wide range of crops is the favorable climate. This study was aimed at evaluating the suitability of the soils for the production of groundnut and to have a detailed soil database for effective land use planning. Soil requirements for groundnut were obtained from past research works and compared with data collected from the survey. The study showed that the soils of the area had formed under climatic environment presently characterized by an annual rainfall of about 1330.20 mm and a mean annual temperature of about 27.80 °C. The soils were well drained to poorly drained. The clay content ranged from 7.20 to 29.30 %, increasing with depth. Organic carbon was low (0.64 %) in the upland, but relatively high when compared with the low (0.62 %) value in the low land. The suitability assessment results showed that although, certain quantities or characteristics such as mean annual temperature, relative humidity and base saturation were optimum for groundnut cultivation, there was however, no highly suitable (S_1) land for groundnut cultivation in the area. All the soils were classified into moderately suitable (S_{2f}) subclass due to their low nutrient levels. COATRF I and II units of the area were moderately suitable (S_{2tf}) due to topography and low soil fertility. COATRF III was limited by its imperfect drainage to marginally suitable subclass (S_{3wf}) for groundnut production. To improve on the level of productivity of the soils for optimal groundnut production, management techniques such as continuous organic matter incorporation and mineral fertilizer application, and efficient use of mineral fertilizers with low levels of chemical inputs with adaption of appropriate irrigation techniques would make dry season farming sustainable.

Key words: evaluation, groundnut, climatic conditions, Makurdi, soils.

Introduction

The broad principles of land evaluation involve comparing the requirements of land use with quality of land thereby assessing the value of each type of land present for each land use (Dent, 1981). Decisions on land use are being based on comprehensive analysis of the production and potentials of natural resources such as climate, soil and hydrology (Abagyeh, 2016). Soil evaluation is very important in this direction as it provides information on the potentials and constraints of land for a defined land use type in terms of crop performance as affected by the physical environment. Soil evaluations are based on knowledge of crop requirements, prevailing conditions and applied soil management methods (Ande, 2011). Soil evaluation for suitability classification quantifies in broad terms to what extent soil conditions match crop requirements under a defined input and management (FAO, 1976). Evaluating the soil enables optimum performance and maximum productivity of the crop. In evaluation, the specific crop requirements will be calibrated with the terrain and soil parameters (Dent, 1981), so that the identified limiting factors could be managed to suit crop requirements and improve productivity. Land evaluation thus, enables management guidelines in order to promote a more sustainable use of the soil and environmental resources (Maniyunda, 2007).

Groundnut (*Arachis hypogaea* L.) is a member of sub-family, papilionaceae of the family Leguminosae. It is believed to be the native of Brazil to Peru, Argentina and China. It was introduced into India during the first half of the sixteenth century from one of the pacific islands of China. Groundnut oil is an edible oil. It finds extensive use as a cooking medium both as refined oil and Vanaspati Ghee. "They are rich in protein and vitamins A, B and some members of B2 group. Nigeria is the largest groundnut producing country in West Africa, accounting for 51 % of production in the region. The country contributes 10 % of total global production and 39 % that of Africa. Between 1956 and 1967, groundnut was the country's most valuable single export crop, exemplified by the famous Kano groundnut pyramids. Groundnut is a major source of edible oil as well as livelihoods for small-scale farmers in Northern Nigeria. Being a labor-intensive crop, it generates employment for the rural poor. It is planted on about 34 % of total cultivated area and contributes to 23 % of household cash revenue. Groundnut products like oil and cake accounted for a significant percentage of total Nigerian export earnings. Before the fossil oil boom, groundnut was one of the major sources of revenue and foreign exchange earnings. However, in the post-1967 period, the combined effects of drought, increasing prevalence of diseases such as rust, leaf spots and groundnut rosette disease (GRD) have caused a decline in groundnut production. The total output of groundnut in 1970 was 1.6 m tons, but fell to 0.47 m tons in 1980. Due to insufficient groundnut stocks, processors and marketers in Kano State source groundnut from as far as Chad Republic.

The year-round demand for groundnut means farmers can increase production without any fear of market glut. Since 1984, production has been increasing at an estimated growth rate of 8 %, resulting both from area expansion (6 %), and increase in productivity of 2 % (Ndjeunga et al., 2010). Hence, the study was to evaluate the soils and climatic conditions

supporting groundnut (*Arachis hypogaea* L.) production in College of Agronomy Research Farm of University of Agriculture Makurdi Benue State

Materials and Methods

Study area

The study was conducted within the teaching and research farm of the College of Agronomy University of Agriculture, Makurdi. The University lies North-east of Makurdi town which is between Latitude 7.45° N and 7.50° N and Longitude of 8.00° E and 9.00° E. Makurdi is in a strategic position in the Agricultural map of Nigeria, producing a wide range of both annual and perennial crops such as groundnut, sorghum, soybean, cowpea, rice, maize, yam, citrus, mangoes and a variety of vegetables; one of the factors responsible for this wide range of crops is the favorable climate (Igomu and Idoga, 2017). Makurdi has tropical climate conditions with distinct wet and dry seasons. The dry season starts from November to March while rainy season starts from April and end in October. In the past, Benue state experiences a bimodal rainfall distribution pattern with one peak in July and another in September. Recent meteorological data point to unimodal pattern with the single peak in August. The mean annual rainfall for Benue state varies between 1000 and 1600 mm. The mean minimum air temperature of Makurdi is 16.20 °C to 17.20 °C during the period of harmattan, which is December to February. The mean maximum air temperature is 37.7 °C in March prior to the onset of rains. The slope of the area is 0 to 5 % and the mean elevation above mean sea level is about 93 m (Ojanuga and Ekwoanya, 1995).

Field studies

Field studies involved taking soil samples using a core sampler as well as the collection of bulk soil samples for laboratory analysis. Soil samples were collected using grid method with a core sampler based on the nature of the slope of the study plot of 600 X 400 meters. Five samples were collected to form composite samples from each of the upper crest location, the mid slope and foot (lower) slope, respectively to enhance proper study of the soil of the areas. The soil samples were described using the pattern outlined in the Soil Survey Manual (2010).

Laboratory analyses

Standard laboratory procedures were employed in the investigation of the physical and chemical characteristic of the soil samples collected from the field. The bulk soil samples collected from the field were air dried. The air-dried samples were gently crushed using mortar and pestle. The samples were sieved through 2 mm and 0.5 mm sieves and used for laboratory analyses. For laboratory analyses like particle size distribution, Boyoucos hygrometer method was used. Electrometric method as described by Hesse (1971) was used for pH analysis. Walkley-Black method as described by Hesse (1971) was used for organic determination. Total nitrogen was determined by the use of macro Kjeldahl method

(Bremmer, 1965). Sodium bicarbonates NaHCO_3 extracting solution Olsen (1965) was used for available phosphorous determination, and exchangeable cations (Ca, Mg, K and Na). Cation exchange capacity was also determined using neutral solution of ammonium acetate method. K and Na in the extracts usually determined using Flame photometer while Ca and Mg are determined using AAS.

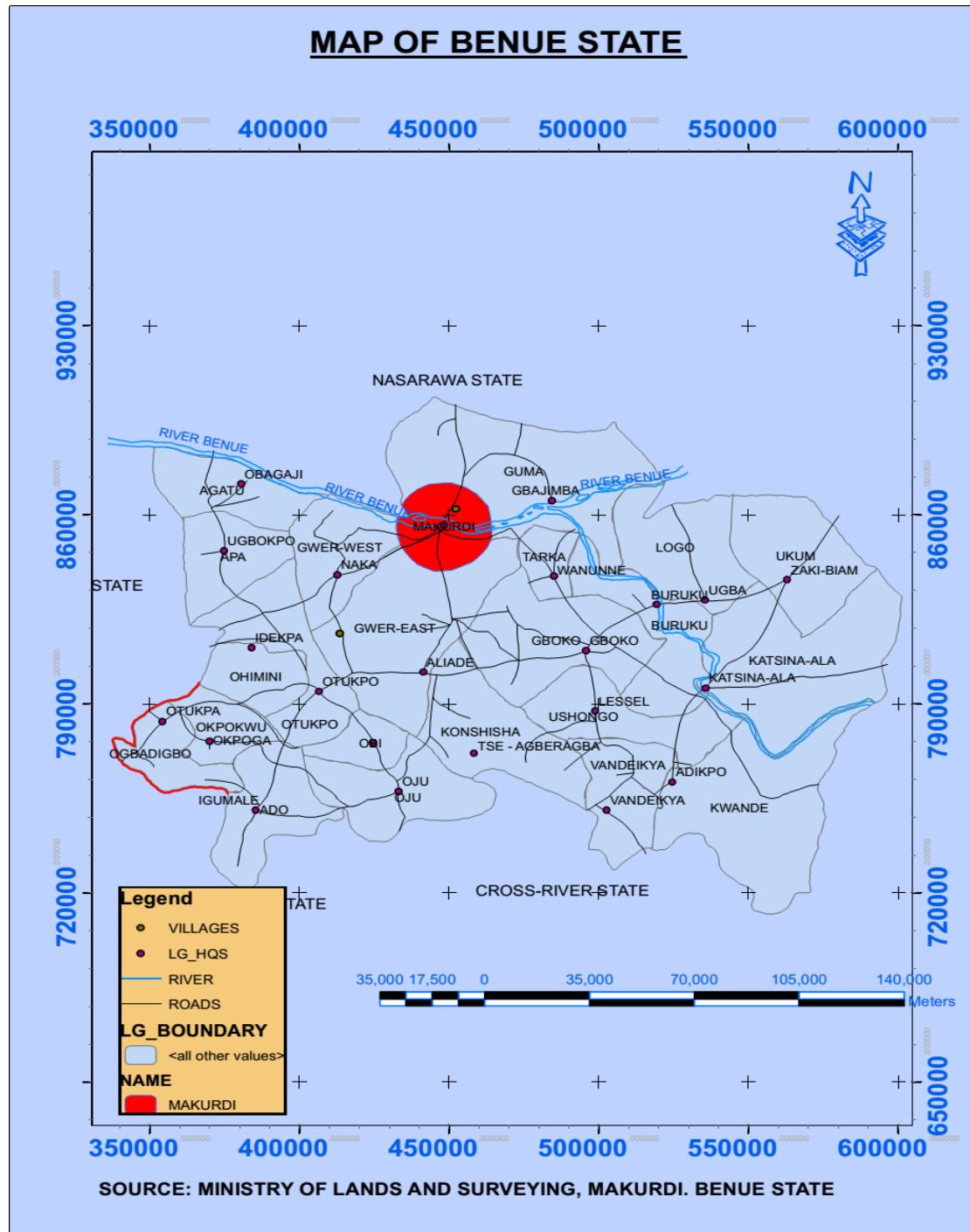
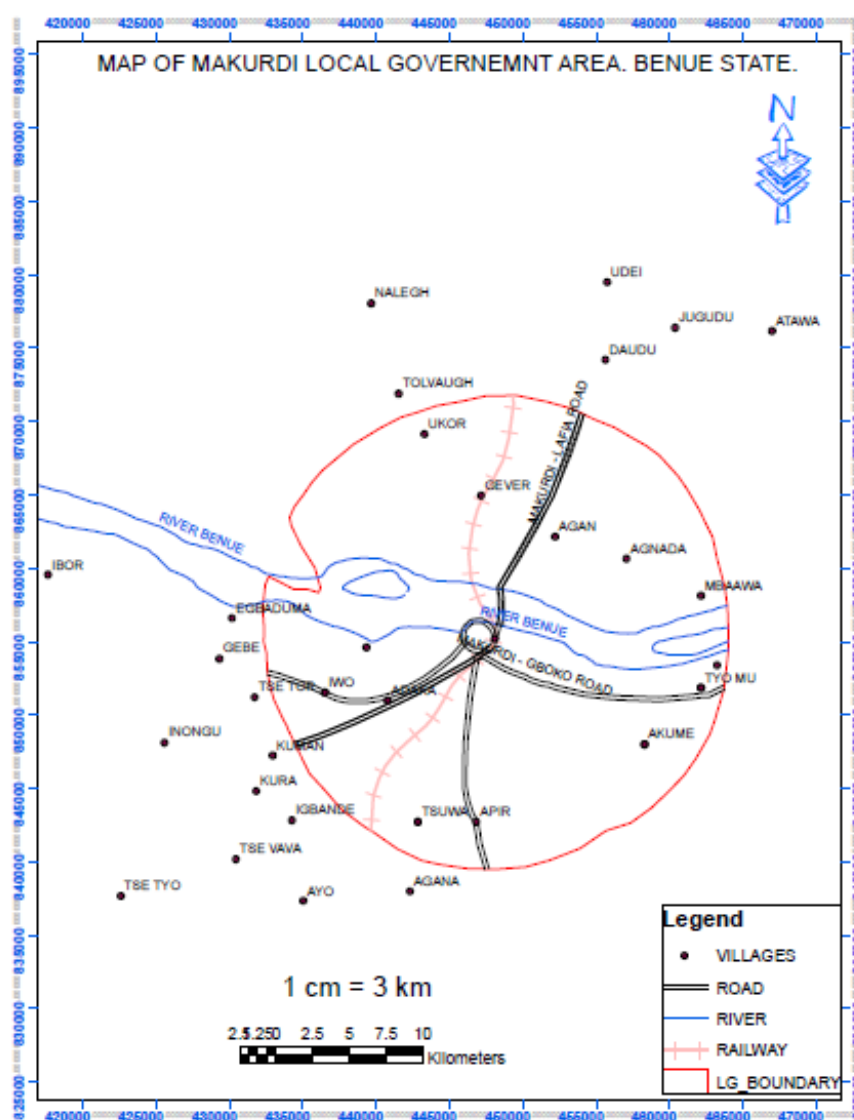


Figure 1. Map of Benue State, Nigeria.

Land evaluation procedures

The conventional parametric method was used for the suitability evaluation of the land (FAO 1976), where soils were placed in suitability classes by matching their characteristics with the established requirements for groundnut (Table 1). The aggregate suitability class indicates the most limiting characteristics of the land. The parameters used for the land quality calculation include rainfall, mean annual temperature, slope, wetness, drainage. While those of soil characteristics included texture, coarse fragment, soil pH. Other fertility indicators were base saturation, organic carbon and available phosphorus.



SOURCE: MINISTRY OF LANDS AND SURVEYING, MAKURDI, BENUE STATE.

Figure 2. Map of Makurdi Local Government area of Benue State.

Table 1. Soil and Climatic Requirement for Suitability of Groundnut (*Aracis hypogaea*)

Land characteristics	Rate	100-95	84-40	39-20	19-0
	Class	S1	S2	S3	N1
Climatic ©					
Annual rainfall	Mm	600-1500	500-1250	450-850	-
Mean Annual Max Temp.	°C	30-35	15-20	21-30	-
Relative humidity	%	50-80	>80	-	-
Length of dry season	Days	120-150	110-130	90-130	-
Topography (t)					
Slope					
	%	0-2	8-Apr	16-Aug	>30-50
Wetness	%	0-4	16-Aug	16-30	>30
Flooding	Class	FO	FI	Aeric	Poor
Drainage	Class	Good	Poor	Poor	Drainage
Soil physical properties (s)					
Texture/structure					
	Class	LS,S	SL,S	LS, S	S
Coarse fragment (0-50cm)	%	<3	15-35	35-50	-
Fertility (f)					
CEC	(cmol/ kg) clay	>24	<16(-)	<16(+)	-
Base saturation	%	>50	20-35	<20	-
pH	Water	5.9-7.0	5.5-8.0	5.0-8.0	-
Organic carbon (OM)	(0-50) %	>2	0.8-12	<0.8	-
Available P	mg/kg	>22	13-Jul	7-Mar	<3
Extractable K	cmol/kg	>0.50	0.20-0.30	0.10-0.20	<0.10
Total Nitrogen	%	>0.15	0.08-0.10	0.04-0.06	<0.08

Key: FO-No Flooding, FI- Seasonal Flooding, FR-Flooding Rare, C-Clay, CL- Clay Loam, LS- Loamy Sand, SL- Sandy Loam, LCS- Loamy Clay Sand, CS- Clay Sand, S- Sand, S1- Highly suitable, S2- Moderately suitable, S3-Marginally suitable, N1- Currently not suitable.

SOURCE: Adesemuyi (2014).

Results and Discussions

The particle size distribution values for the soil mapping units are shown in Table 2. The values revealed the sandy nature of all the soil units. Soils of units I and III generally have loamy sand surface texture while, soil unit II had sandy loam surface texture. The sand fraction of the three soil units ranged from 70.64 to 71.08 %. This high fraction of sand could be attributed to the nature of the parent material (sandstone). Sand fraction decreased with depth in all soil units. The clay content of the soils was moderate to high ranging from 14.92 to 16.20 %, while silt fraction ranged from 13.0 to 14.0 %. Because of illuviation, the clay content of the soils was higher in the mid crest than the top crest. The weak fine to medium crumbs of upper crest of all soil units (Table 2) could be attributed to their low level of organic matter and sandy nature of the soils. In the entire field, the three units had moderate to strong, medium to coarse sub-angular blocky structures. This may be attributed to the corresponding increase in clay content in the sub soils.

The pH (H₂O) of the soils ranged between 6.10 and 6.16 (Table 2) indicating strong to slightly acid (USDA, 2010). There was a general tendency among these soils to have higher pH values at surface, which may decreased with depth. Ojanuga and Ekwoanya (1995) attributed the slightly higher pH in the upper most soil horizon to the accumulation of exchangeable calcium (Ca) and magnesium (Mg) derived from plant roots and litter decomposition, as well as biogenetic cycling of bases. The pH values of the soil units I and III were higher than those of Unit II. As the cations are leached, hydrogen ion (H⁺) from water (H₂O) replaces the leached cations in the exchange complex to balance the charge. Soil acidity is known to affect most soil nutrients especially P, N, S, and micronutrients (Agbede, 2009).

The organic carbon (Table 2) was low according to the ratings of Esu (1991) with values ranging from 0.59 to 0.64 %. These values may decreased with depth in all the three Soil Units due to the concentration of plant roots and residue on the soils. The low organic carbon content of these soil units could be attributed to annual bush burning in the area as well as the native vegetation cover and climate. According to Igomu and Idoga, (2017), drainage appeared to have strong influence on the organic carbon content of the soil. Earthworms and other organic fauna increase organic carbon content of the soil by breaking and biochemically altering fresh organic matter through mixing with inorganic materials and later excreting them to form a moist homogenous blend of the organic and mineral matters, which prevents rapid loss of humic compounds (Esu, 1982). More earthworm casts were seen on the surface of soil unit II than units I. Total nitrogen values ranged from 0.13 to 0.18 % for all the soil units studied. The distribution of total nitrogen follows the same pattern as organic carbon in topo sequence. Osujieke et al. (2018) revealed that savannah soils are generally low in total nitrogen. This is due to the low organic carbon content of the soils of the savannah agro-ecological zone. It is obvious that climate, vegetation and human activities contribute to the low level of nitrogen. The available phosphorus of the soil had values ranging from 2.8 to 3.2 mg/kg and were generally low when compared with the ratings of Chude et al. (2011). The surface values of the amount of available phosphorus, which may decreased with soil depth shows that much of the available P is in organic forms associated with organic matter.

The values of Ca^{2+} , K^+ and Na^+ were low while Mg^{2+} was moderate when compared with the ratings of Landon (1991) in all the soil units. The low values of exchangeable bases of these soils maybe due to intensity of weathering and lateral translocation of bases. The amount of exchangeable calcium (Ca) ranged between 2.5 and 3.0 cmol (+)/kg of soil. Magnesium (Mg) ranged between 2.3 and 2.7 cmol (+)/kg of soil. Potassium (K) ranged between 0.24 and 0.27 cmol (+)/kg of soil while Sodium (Na) ranged between 0.21 and 0.24 cmol (+)/kg of soil. The predominance of Ca over the other cations in these soils may be because of all the exchangeable cations, Ca is least easily lost from the soil environment (Brady, 1974). The CEC of the soil ranged from 6.37 to 7.31 cmol/kg of soil. The lowest CEC values were recorded in unit III owing to their low organic carbon content and perhaps low clay content. Donahue et al., (1976) reported that some sandy soils of the tropics with dominant clay might have low CEC hence, low fertility. Base saturation by sum of cations ranged between 82.42 and 85.51 % which is rated very high (Idoga and Ibrahim, 2012). The high base status showed that the soils had high native fertility, which is confirmed by the luxuriant growth of the vegetation of the soil.

Land Suitability Evaluation

The overall methodology followed involved the selection of attributes relevant to groundnut production, generation of data layers, weighting and overlaying of the data layers to generate a land suitability map for groundnut production. Elevation dataset was used as proxy for climatic variables (rainfall and temperature) and it was generated by reclassifying the digital elevation model (DEM). The distance dataset representing accessibility was generated using the Euclidean distance tool. Each data layer was reclassified into suitability classes based on groundnut requirement. The suitability levels assigned to each dataset were defined based on literature, expert knowledge, observation and practical experiences. The suitability levels were ranked as highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable based on the suitability classification structure (Adesemuyi, 2014). The datasets generated were finally combined using the weighted sum overlay to generate the land suitability map for rainfed groundnut production. The matching of land characteristics used for suitability ratings of sites for groundnut (*Arachis hypogaea*.) production in Makurdi (Table 3) with land and soil requirements for suitability rating of groundnut (Table 1) resulted in the suitability classes of the soil mapping units as shown in Fig. 3. The region was optimal or near optimal in mean annual temperature, relative humidity, length of dry season, slope and base saturation.

Textural classes of the COATRF I soils ranged from loamy sand to sandy loam, thus, considered moderately suitable (S2s) for the cultivation of groundnut. The soil texture for optimum groundnut performance is sandy loam or loam (Sys, 1985). However, topography and low soil fertility levels limited the soils into the moderately suitable (S2tf) subclass for groundnut production. Based on these assessments, none of the soils was considered highly suitable for groundnut cultivation in the area. Soils of COATRF I and II were classified into moderately suitable (S2f) subclass as a result of their low nutrients status

Table 2. Physical and chemical characteristics of the soils

S/NO	Sample Identity	Sand %	Clay %	Silt %	pH H ₂ O	OC %	Av.P mg/kg	N %	K	Na	Mg (cmol/kg)	Ca	CEC
1	Upper crest	70.8	16.2	13	6.12	1	3.2	0.18	0.27	0.24	2.7	3	7.31
2	Mid slope	71.08	14.92	14	6.16	1	2.8	0.13	0.24	0.21	2.3	2.5	6.37
3	Foot slope	70.64	16	13.36	6.1	1	3.1	0.15	0.26	0.24	2.6	2.8	6.9

OC= organic carbon, Av.P= available phosphorus, CEC= cation exchange capacity, BS= base saturation

Table 3. Land characteristics used for suitability rating of sites for groundnut (Arachis hypogaea) production in Makurdi

Land characteristics		Unit	COATRF 1	COATRF 2	COATRF 3
Climatic ©					
Annual Rainfall		mm	1000-1600	1000-1600	1000-1600
Mean Annual Max. Temp.		°C	37.7	37.7	37.7
Relative Humidity		%	>80	>80	>80
Length of Dry Season		Days	120-150	120-150	120-150
Topography (t)					
Slope		%	0-5	0-4	0-4
Wetness (w)					
Flooding		Class	FO	FR	FI
Drainage		Class	WD	WD	ID
Soil Physical Properties (s)					
Texture/Structure		Class	95	90	80
Coarse fragments(0.50cm)		%	<3	15-35	35-55
Fertility (f)					
CEC		(cmol*kg ⁻¹)	7.94	8.03	10.48
Base Saturation		%	93	82	79
PH		Water	5.5-7.0	5.5-8.0	5.0-8.0
Organic matter (OM)		-0.50%	1.27	1.09	1.21
Avail. P		cmol*kg ⁻¹	3.64	3.07	3.26
Extractable K		cmol*kg ⁻¹	0.25	0.27	0.29
Total Nitrogen		%	0.078	0.069	0.074
COATRF- College of Agronomy Teaching and Research Farm.					
FO- No Flooding, FI- Seasonal Flooding, FR- Flooding Rare, WD- Well Drained, WI- Poorly Drained.					

Table 4. Land characteristics used for suitability ratings of sites for groundnut (*Arachis hypogaea L.*) production

Land Characteristic	COATRF 1	COATRF 2	COATRF 3
CLIMATE ©			
Annual Rainfall	100=S1	100=S1	100=S1
Mean Annual Max. Temp.	100=S1	100=S1	100=S1
Relative Humidity	100=S1	100=S1	100=S1
Length of Dry Season	100=S1	100=S1	100=S1
Topography (t)			
Slope	80=S2	84=S2	95=S1
Wetness (W)			
Flooding	100=S1	85=S2	71=S3
Drainage	95=S1	75=S2	65=S3
Soil Physical Properties			
(s)	95=S1	90=S2	80=S3
Texture/Structure			
Coarse Fragment (0-50cm)	90=S2	90=S2	90=S2
Fertility (f)			
CEC	65=S3	69=S3	71=S3
Base Saturation	90=S1	82=S1	79=S1
PH	90=S1	80=S2	38=S3
Organic carbon (OC)	84=S2	75=S2	80=S2
Avail. P	65=S3	70=S3	15=S3
Extractable K	75=S2	80=S2	54=S3
Aggregate Suitability	S1tf	S2tf	S3wf
Class			

KEY: COATRF-Collage of Agronomy Teaching and Research Farm, S1- Highly suitable, S2- Moderately suitable, S3- Marginally Suitable

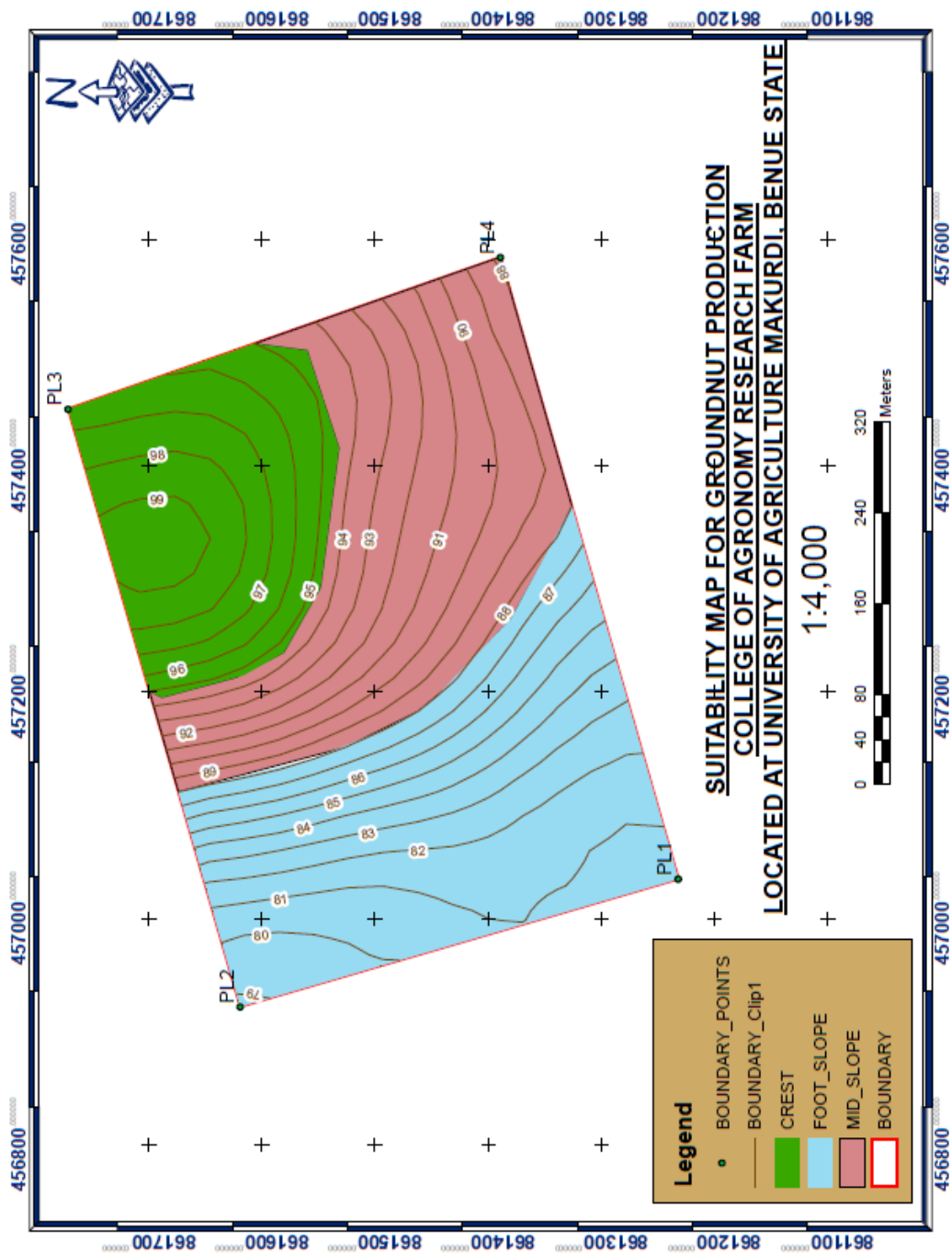


Figure 3. Suitability map for groundnut production in COATRF Makurdi

Table 5. Metrological data of mean values of maximum and minimum temperature in degree celsius, relative humidity and total amount of rainfall in milimetres (mm) in Makurdi

CLIMATIC DATA FOR BENUE STATE															
Month		J	F	M	A	M	J	J	A	S	O	N	D	T	M
Temp ° (C)		2015	38.80	36.30	35.80	36.90	35.00	32.70	30.90	30.90	32.40	34.00	33.70		
	Max	2016	35.40	38.40	35.70	34.00	33.40	31.80	30.90	30.60	32.50	35.30	35.40		
		2017	36.40	38.10	39.50	36.30	33.20	32.10	31.00	30.10	31.10	34.60	36.00	35.60	
	Min	M	36.80	37.80	37.00	35.00	33.80	32.20	30.90	30.50	30.90	33.20	35.10	34.90	408.60 34.00
DAY		2015	17.90	23.80	24.20	24.20	24.00	24.40	23.60	23.00	23.30	23.80	17.50		
		2016	21.70	26.00	25.30	24.10	23.60	23.20	23.50	23.10	22.40	23.40	23.40		
		2017	20.30	20.30	26.80	25.70	24.50	23.80	22.50	22.90	23.70	22.60	22.90	18.20	
	M		19.90	23.40	25.40	24.70	24.00	24.00	23.20	23.00	23.50	22.70	23.40	19.70	276.90 23.00
NIGHT		2015	40.00	71.00	70.00	65.00	72.00	76.00	82.00	85.00	79.00	69.00	27.00		
		2016	27.00	29.00	73.00	73.00	79.00	80.00	84.00	87.00	84.00	81.00	52.00		
		2017	49.00	31.00	59.00	70.00	78.00	80.00	84.00	86.00	82.00	69.00	51.00		
	M		38.70	43.70	67.30	69.30	76.30	78.70	83.30	86.60	83.70	79.30	43.30	833.60 69.50	
RH (%)		2015	23.00	41.00	43.00	39.00	53.00	50.00	68.00	71.00	66.00	66.00	19.00		
		2016	15.00	20.00	52.00	57.00	57.00	66.00	66.00	70.00	72.00	65.00	26.00		
		2017	24.00	11.00	31.00	47.00	63.00	68.00	70.00	74.00	70.00	40.00	31.00		
	M		20.70	24.00	42.00	47.70	57.70	61.30	68.00	71.70	70.30	57.00	25.30	617.00 51.50	
Month		J	F	M	A	M	J	J	A	S	O	N	D	T	M
Rainfall (mm)		2015	00.00	118.80	3.90	17.70	37.20	123.60	139.70	339.10	127.30	82.90	16.80	00.00	1007.00
		2016	00.00	00.00	47.60	91.10	238.00	49.40	215.60	213.80	268.90	116.10	00.00	00.00	1240.50
		2017	00.00	00.00	00.00	86.30	245.80	123.90	95.70	224.30	158.70	73.90	0.60	00.00	1009.20
	M		0.00	39.60	17.20	65.10	173.70	98.90	150.30	259.1	184.90	90.90	5.80	0.00	1085.57

Key: Temp. = Temperature; RH = Relative humidity, M = mean

Conclusions

This research offered some valuable insight with outcomes vital to groundnut production in Federal University of Agriculture Makurdi, Benue State of Nigeria. The suitability assessment results showed that although, certain qualities or characteristics such as mean annual temperature, relative humidity and base saturation were optimum for groundnut cultivation, there was however, no highly suitable (S1) land for groundnut cultivation in the area. Soils of COATRF I and II was classified into marginally suitable (S2f) subclass, due to their low nutrients' levels. COATRF I and II Units of the area were moderately suitable (S2tf) due to topography and low soil fertility. It can further be concluded that the generated land suitability map with overall classification accuracy which was 320 meters of the farm land can rightly be used as a guide in decision making for groundnut production. Therefore, it is conclusive that the soils of College of Agronomy Research Farm Federal University of Agriculture Makurdi, is moderately suitable for groundnut production.

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Role of Year-Round Plant Cover and Agro-Technical Measures on Arable Land for Improvement of Some Water-Physical Parameters of the Eutric Fluvisol



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Abstract

Intermediate crops used for plant cover or green manure affect a positive direction of different soil indicators: organic matter content, soil structure, reduced bulk density and soil strength, limit the risk of erosion, eventually leading to a reduction in soil and moisture losses. The purpose of the present study was to establish the role of year-round cover of arable land with crops of cereals and forage crops and agro-technical measures to improve some water-physical parameters of Alluvial-meadow soil (Fluvisol) in crop rotations.

The study was carried out in the experimental field of Tsalapitsa, Plovdiv at the experimental base of “N. Pushkarov” Institute of Soil Science, Agrotechnology and Plant Protection, using the standard block method. In the next crop rotation - maize (*Zea mays*, L.) – barley (*Hordeum vulgare*, L.) – maize (*Zea mays*, L.), were included intermediate crops (winter and spring) grown for green mass before the main spring crop maize (*Zea mays*, L.). From the obtained results, it was found that when in crop rotations were included winter precultures the risk of negative influence of climatic factors on the physical characteristics of the Eutric Fluvisol is reduced. Despite leaving the stubble from the pre-sowing crop, after spring mixture crops, there is an increase in the values of bulk density and soil strength. These results are probably due to the poor condition of the soil that was plowed in the spring and insufficient time to carry out the sowing. The study confirms the role of soil cultivation in improving the studied physical parameters - moisture content, bulk density, and soil strength.

Key words: intermediate crops, crop rotation, soil water-physical parameters

Introduction

The sustainable management of soils in agricultural systems places great demands on the research related to the mechanisms for maintaining all quality parameters of the soil (physical, chemical and biological) in optimal limit values (Dumanski, 1991; Krastanov, 2006). The main task is to achieve long-term maintenance of soil fertility through the use of

natural remedies and organic materials - organic fertilization, plant residues, green fertilization, applied within a well-structured crop rotation (Mitova et al., 1999; Estrade et al., 2010, Dimitrov et al., 2013; Karlen et al., 2013, Griffith et al., 2013). These agricultural practices ensure the return to the soil of a significant amount of biodegradable biomass and are the basis for the construction of highly productive ecological systems, together with their positive significance for limiting ecological risks. In this aspect, the intermediate crops used for plant cover, which occupy the fallow period before the spring crops and are sown to be incorporated into the soil (green manure) or left as mulch, positively change the various soil indicators - the organic matter, the soil structure and the stability of the soil aggregates, bulk density, soil strength, reduce the risk of erosion, which leads to reduced losses of soil and moisture (Marinari et al., 2000; Mitova et al., 2015). According to research by Tsvetkova et al. (1995) green manure in conventional crop rotation improves basic soil physical parameters and reduces erosion losses. In addition to the above-ground biomass, a significant amount of root mass remains in the soil, which is subject to mineralization. According to (Talgre et al., 2010), the root mass of leguminous crops for green manure constitutes 37-54% of the total biomass. The results of long-term field experiments have been used to increase the effect of their management, for the structural formation, stabilization of the composition and improvement of the water-physical parameters of the soil (Ulrich et al., 2006; Dimitrov et al., 2011; Abdollahi et al., 2014; Kinoshita, 2017). The provision of year-round plant cover of the arable land makes it possible to protect the soil surface from the risk of erosion processes and preserve soil fertility (Milev & Iliev 2014; Mitova et al., 2011; Laird et al., 2013). Apart from being a soil protection agent, plant residues from the cultivated main and intermediate crops in field crop rotations are a source for increasing the content of organic matter in the soil. (Pommeresche et al., 2006; Gerasimova, 2018).

The present study aims to establish the role of year-round plant cover of the arable land with crops of cereal and forage crops included, crop rotation with cover crops as well as the agrotechnical measures for their cultivation to improve some water-physical parameters of Alluvial-meadow soil (Fluvisol).

Material and Methods

The researched area was located at the experimental field of ISSAPP "N.Pushkarov" in the village of Tsalapitsa, Plovdiv region, South Bulgaria for the period 2016-2018.

The experiment is based on the block method – on long plots on an area of 0,3 ha, in four replications with a size of the experimental plots of 40 m². The study included year-round coverage of the soil surface with crops of cereals and grass forage crops and a control variant without used coverage crops. During the study period crop rotation included cover crops for vegetation before the main spring trench crop – maize (*Zea mays*).

The following 4 variants (A₁; A₃; A₅ and A₆) were included in the study with alternating preculture - maize (*Zea mays*) – barley (*Hordeum vulgare*) – preculture - maize (*Zea mays*):

Table 1. Crop rotation 2016-2018 years

Variants	2016	2017	2018
V A ₁	Preculture (winter peas + barley) - maize	Barley	Preculture (winter peas + barley) - maize
V A ₃	Preculture (spring peas + spring barley) – maize	Barley	Maize
V A ₅	Control - maize without pre-crop	Barley	Maize
V A ₆	Perennial wheat-bean mixture (sainfoin (60%) + hedgehog head (20%) + timothy (20%))	Perennial wheat-bean mixture (sainfoin (60%) + hedgehog head (20%) + timothy (20%))	Perennial wheat-bean mixture (sainfoin (60%) + hedgehog head (20%) + timothy (20%))

Variant A₁ - preculture (winter peas (*Pisum sativum*) + barley (*Hordeum vulgare*)) - maize (*Zea mays*) for grain – barley (*Hordeum vulgare*) — preculture (winter peas (*Pisum sativum*) + barley (*Hordeum vulgare*)) - maize (*Zea mays*) for grain.

Variant A₃ - preculture (spring peas (*Pisum sativum*) + spring barley (*Hordeum vulgare*)) – maize (*Zea mays*) for grain - barley (*Hordeum vulgare*) - maize (*Zea mays*) for grain.

Variant A₅ - control – maize (*Zea mays*) for grain without pre-crop - barley (*Hordeum vulgare*) – maize (*Zea mays*) for grain.

Variant A₆ - perennial wheat-bean mixture (sainfoin (*Onobrychis sativa*) (60%) + hedgehog head (*Dactylis glomerata*) (20%) + timothy (*Phleum pratense*) (20%).

The variants with winter cereal-bean mixture and variants with spring cereal-bean mixture are included in crop rotation. Variant A₅ is used for control. A perennial grass field (A₆) was also included in the study, which was also used as a control variant.

According to the stock of soil with nutrients after agrochemical analysis in both studied crops for barley, was used fertilizer norm N₁₂₀P₁₀₀ per ha, and maize – N₁₄₀P₁₀₀.

For winter cereals phosphorus and nitrogen fertilizers are imported in the autumn with the last pre-sowing tillage; for barley nitrogen fertilizer is introduced at 1/3 rate pre-sowing and 2/3 of the norm as feeding at the end of the „tillering“ phase; for maize – phosphorus is imported for preculture (except for the control variant – pre-sowing), and nitrogen - with pre-sowing tillage.

The tillage system includes plowing + spring tillage (shallow plowing or chiseling) for the main crop and pre-sowing tillage for cereals with a heavy disc harrow. The main tillage for maize compacted with winter mixtures was carried out in autumn, and the one compacted with spring mixtures in spring, in order to leave unploughed stubble from the predecessor - barley.

The following water-physical parameters have been determined:

- moisture content of the soil (%) - by the weight method, as a percentage of the weight of the soil, through 10 cm, at a layer depth of up to 60 cm;
- bulk density of the soil in g/cm^3 - according to Kaczynski's weight method, with rings of 100 cm^3 per layer depth up to 40 cm, through 10 cm layer thickness.
- soil strength – with penetrometer with falling weight type DORNII, with a cone angle of 30° , and then 5 cm. in depth to 40 cm;

The climate in the area is hot with dry summers and mild winters and irregular rainfall distribution (Levicharska, 1991). The period accepted as a norm 1961-1990 has an amount of precipitation of 492 mm. The average annual air temperature is $12.5\text{--}12.8^\circ\text{C}$, in July – 23.4°C , and in January it is around 0°C . In the study area, the soil is Alluvial-meadow (Eutric Fluvisol), (IUSS Working Group WRB, 2015). This type of soil is used for intensive agriculture. The soil profile has a coarse texture, low water holding capacity and fairly high water permeability, which creates conditions for active migration of chemical elements along the profile. The arable horizon has the following mean characteristics: light texture, low clay content (18.6%), bulk density between 1.54 and 1.66 g.cm^{-3} , slightly acidic reaction pH H_2O (6.0), total nitrogen (0.052%), humus content - 1.23%, and cation exchange capacity – $22.4 \text{ cmol.}100 \text{ g}^{-1}$ (Stoichev, 1997).

The weighted average value of the capillary field capacity for the layer 0-100 cm is 19.6%, the wilting moisture is 11.1%, and the productive water is 8.4%. With these values of the indicators, the one-meter soil layer retains at field capacity a total of $306 \text{ m}^3/\text{da}$ of water, 176 m^3 of non-productive water, and only 131 m^3 of plant-usable water reserve. According to the indicator of usable water reserves, this soil type can be referred to as poorly stocked.

The mathematical-statistical analysis of the experimental data was performed with the statistical program SPSS.

Results and Discussion

During the experimental period, significant dynamics were established in the values of the studied physical parameters of the soil type Alluvial-meadow (Eutric Fluvisol).

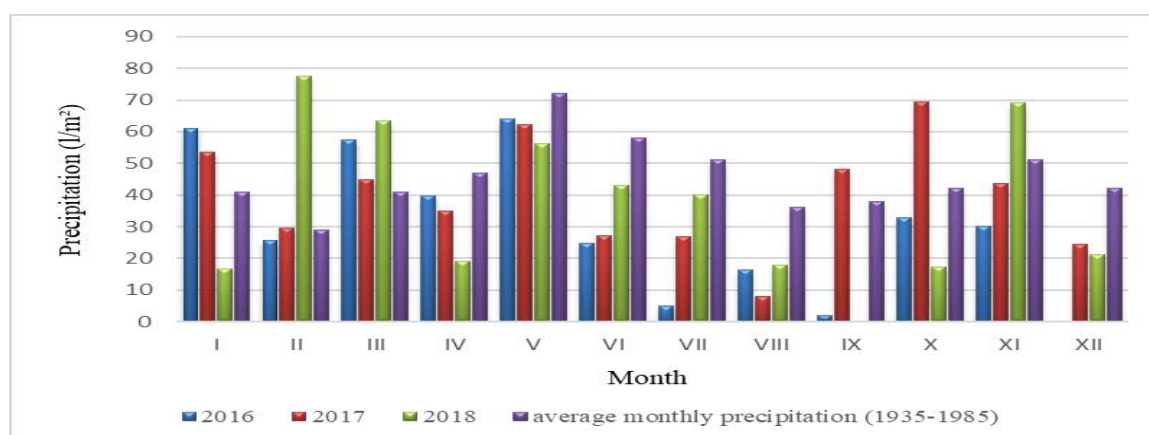


Figure 1. Monthly amount of precipitation in 2016-2018 and for a long-term period (1935-1985), (l/m^2)

Soil moisture content.

The content of soil moisture is a basic physical parameter on which the dynamics of the processes taking place in the soil depend, as well as the emergence, growth, and development of cultivated crops. During the study period, lower precipitation values were found for the study years compared to the long-term precipitation database (Figure 1).

After the experiment was set in the autumn of 2015, low content of soil moisture in the arable layer was reported - around wilting moisture (4-6%). No significant differences in study variants were found. In the spring of 2016, soil moisture was measured before the harvest of the winter and after the emergence of the spring mixture crops and the beginning of the vegetation in the perennial mixture. The data shows that as a result of the rainwater, the values for the parameter are significantly higher than those reported in the autumn. The content of soil moisture has the highest values in the variant with preculture - winter mixture peas + barley (A_1) - from 12.34 to 15.98% (Figure 2). Compared to the variant (A_5) – without preculture, the differences in the 20-60 cm layer are from 1.40% to 2.14%, and in the 10-20 cm layer the trend is the opposite. The obtained lowest soil moisture was in the variant with a perennial mixture crop, which can be explained by a higher consumption of moisture than the plants that have started their vegetative development.

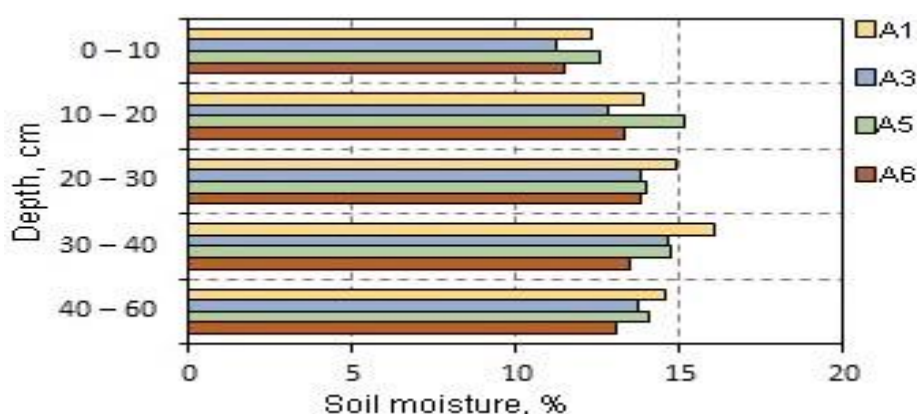


Figure 2. Content of soil moisture by weight (%) - during the spring period of 2016

The moisture content in the soil marks significant changes after the sowing of maize in the variants with spring mixtures and in the crop stage "3-5 leaf", in the variants with winter mixtures, and in the without preculture variant. The humidity was increased by 5.5% to 7.25%, except for the surface 0-10 cm layer, where with drying the values increased to 4.0%. The highest values for the parameter were found in the variant with winter mixtures, as in the layer 30-40 cm the differences compared to the other variants were statistically proved with a probability of error $p < 1\%$. According to research by Mitova et al., (2011), the presence of plant residues in the variants with an intermediate crop for green manure helps to limit the loss of moisture in the high summer temperatures (Mitova et al., 2011).

The soil moisture has the lowest values in the variant without preculture - 17.21% to 21.60% (Figure 3b).

During the maize tasseling phase (June, July) the rainfall was a little 5 to 15 mm, during which drought occurred (Figure 1). As a result of the drought that occurred after the

tasselling phase (for variants A₃ and A₅ - phase 9-10 leaves) the moisture content in the soil marks a steady downward trend (Figure 3a). The largest differences in the values compared to the previous reading were found in the layers 0-20 cm and 40-60 cm of the Eutric Fluvisol. In the plowed layer, the low values for the parameter are the result of increased evaporation from the increased atmospheric and soil temperature, and the deepest layer of the studied profile is probably due to the movement of moisture by capillary.

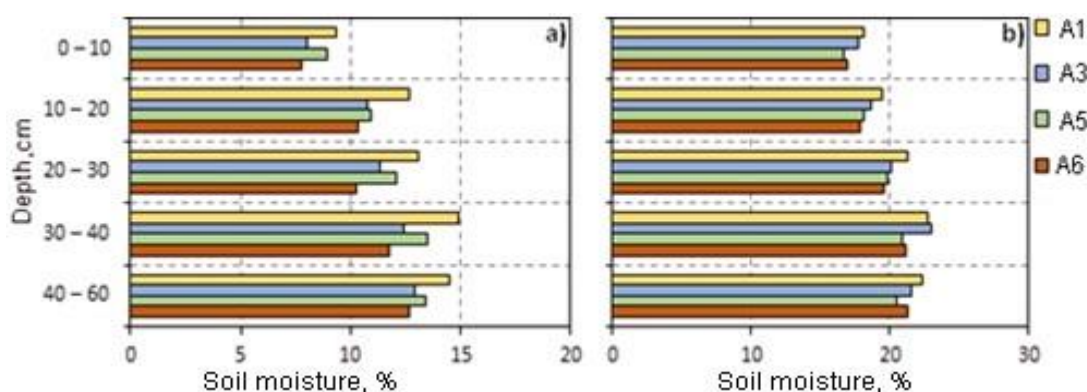


Figure 3. Content of soil moisture by weight - maize 2016 a) phase “tasselling”; b) phase “3-5 leaf”

In the layers 10–20 cm and 30–40 cm, the differences in soil moisture between the variant compacted with winter pre-crops (A₁) and the other variants are significant with a probability of error $p < 5\%$. Most significant in this phase is the influence of crop rotation on the percentage of moisture content in the soil – 92,49% (Table 2).

Up to the wax maturity phase, the maximum values are 11.74% and 11.83% reported in the 30-40 cm layer of the compacted variant (A₅). The lowest moisture content is in the deeper layers of the studied profile in the variant with the perennial mixture (A₆), which is probably due to the small amount of rainwater and the higher consumption of the root system of plants.

Table 2. Dispersion analysis of moisture content – maize “tasselling” phase 2016

Source of variation	Sum of Squares	Sum of Sq. %	Value of the ch.	Medium Sq.	F-rate	Sign. Level (p)
Depth (D)	68.2	2,15	4	17.05	15.672	.000***
Tillage (O)	72.402	2,28	1	72.402	66.551	.000***
Rotation (S)	2936.501	92,49	1	2936.501	2699.172	.000***
D*O	25.022	0,79	4	6.256	5.75	.001***
D*S	16.143	0,51	4	4.036	3.709	.012 *
O*S	7.957	0,25	1	7.957	7.314	.010 **
D*O*S	5.143	0,16	4	1.286	1.182	.333 -
Error	43.517	1,37	40	1.088		
Total Sum	3174.885		59			

SPD 5%=1,722

SPD 1% =2,303

SPD 0,1%=3,025

In the next crop in crop rotation – barley (2017), the reported moisture content in the “tillering” stage is 60-70% of maximum soil moisture, except for the surface layer 0-10 cm, where it is below 50% of maximum soil moisture. The low values for soil moisture are due to the lack of precipitation in the spring (Figure 1). The comparison between the variants in the amount of moisture shows higher values in the variant without preculture - from 5.95% in the surface 0-10 cm layer to 12.16% in the layer 40-60 cm (A₅). There is evidence of differences in the layers 30-40 cm and 40-60 cm compared to variant A₃, and only in the deepest profile layer in variant A₆ (Figure 4a).

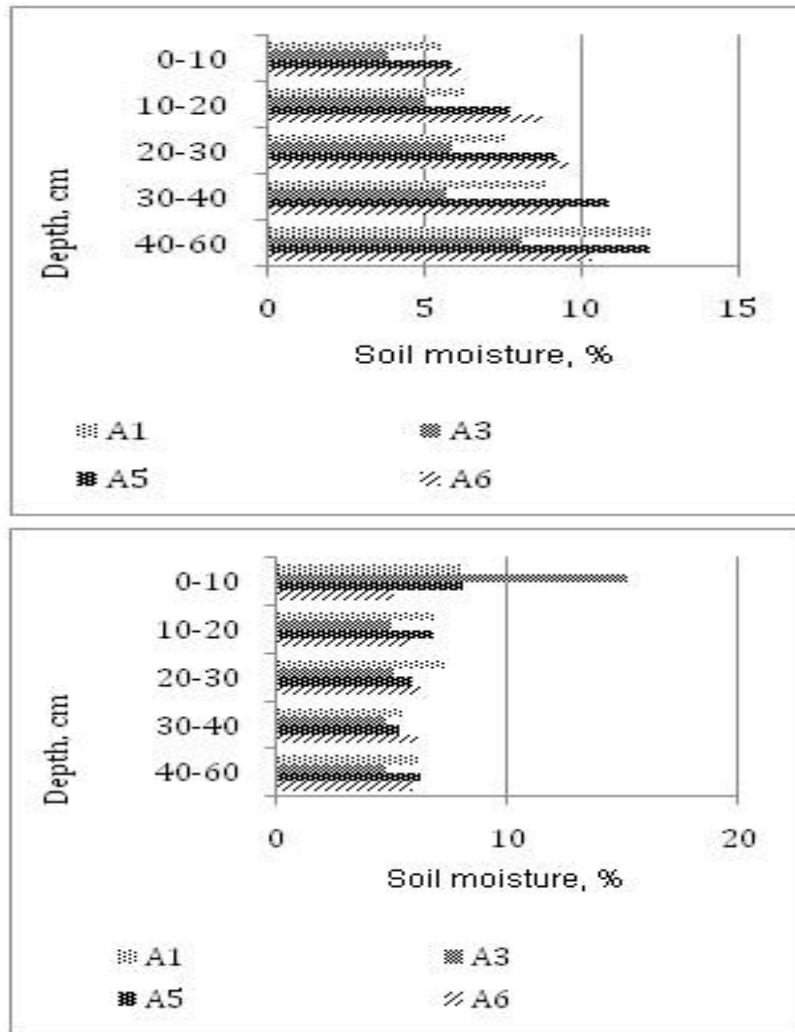


Figure 4. Soil moisture content in weight % barley 2017 a) phase “tillering”
b) phase “head emergence of a class”

Table 3. Dispersion analysis of moisture content –barley “tillering” phase 2017

Source of variation	Sum of Squares	Sum of Sq. %	Value of ch.	Middle Sq.	F-rate	Sign.Level (p)
Depth (D)	31.269	4,72	4	7.817	11.797	.000***
Tillage (O)	0.928	0,14	1	0.928	1.4	.014**
Rotation (S)	554.01	83,58	1	554.01	836.081	.000***
D*O	6.767	1,02	4	1.692	2.553	.054*
D*S	38.128	5,75	4	9.532	14.385	.000***
O*S	0.953	0,14	1	0.953	1.438	.238 -
D*O*S	4.288	0,65	4	1.072	1.618	.189 -
Error	26.505	4,00	40	0.663		
Total Sum	662.847		59			

SPD5% =1,344

SPD1% =1,798

SPD 0,1%=2,361

When taking into account the soil moisture in the “head emergence of a class” phase of barley, higher values were reported in the layer 0-10 cm, as the highest is in the variant barley after spring mixtures (A₃)- 13.5% (Figure. 4b). Lower values of moisture were reported in the layer 30-40 cm, which is due to poor water permeability as a result of soil compaction. In the variant with perennial grasses, uniformity in the moisture content in the layer of 10-60 cm is established, which is due to the lack of moisture inflow from the deeper (below the measured profile) soil layers.

In the next 2018, in stage "3-5 leaf" of maize, a deficit of soil moisture is established. This led to opposite trends compared to previous years in the measured values by survey variants. The parameter in variant A₃ (after spring mixtures) has larger dimensions, probably due to the earlier phase of maize development ("second leaf" stage) and lower consumption of productive moisture by the plants. Differences in the measured values at depth over 40 cm in this variant compared to the other variants were proved at $p < 1\%$. This trend is maintained in the phase of "tasseling" of plants from the variants with spring mixture and control. This fact confirms the assumption that in variant A₃ the higher values for soil moisture content are due to lower consumption by less developed plants. The lowest values are reported in the variant with perennial grass mixture - between 4% and 6%, which is due to drying as a result of elevated temperatures (Figure. 5a). Another reason is the stronger compaction of the soil in the whole studied layer due to the lack of tillage. Most significant in this crop stage is the influence of crop rotation on the percentage of moisture content in the soil (Table 4; Figure 5a).

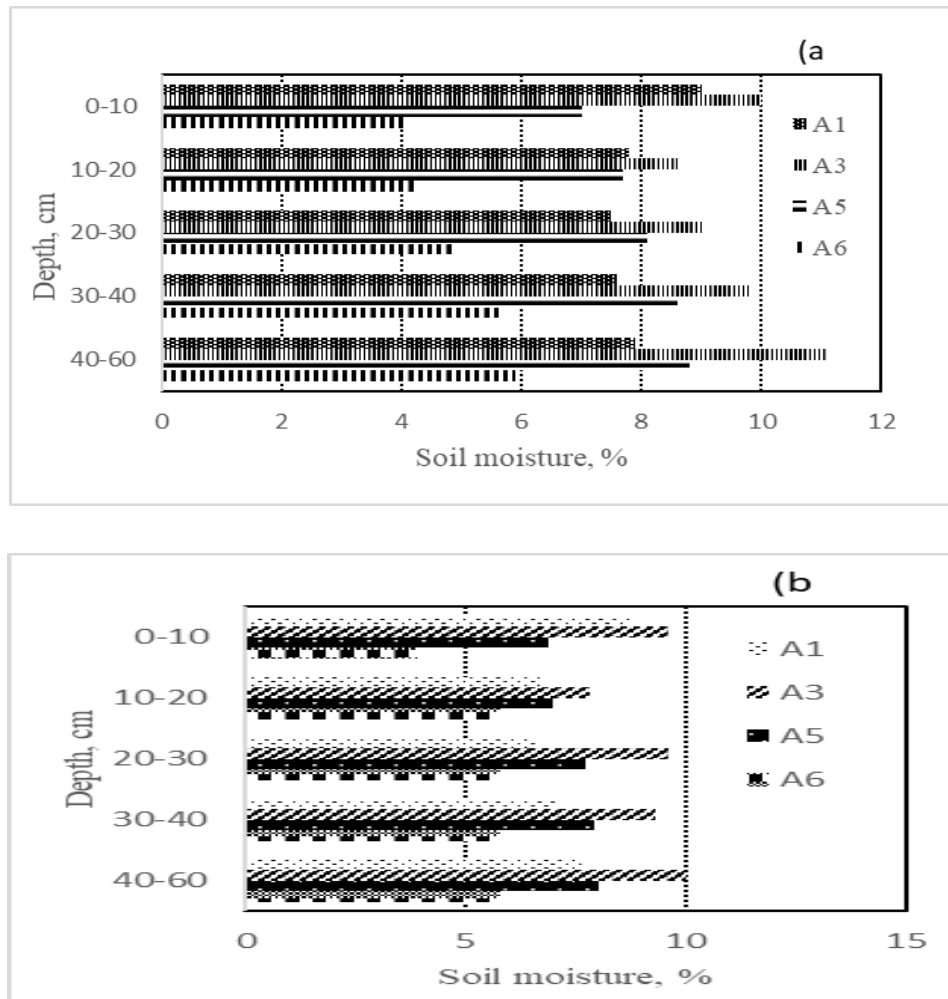


Figure 5. Content of soil moisture by weight % - maize 2018
a) phase "3-5 leaf"; b) phase "tasselling"

Table 4. Dispersion analysis of moisture content – maize "tasselling" phase 2018

Source of variation	Sum of Squares	Sum of Sq. %	Value of ch.	Middle Sq.	F-rate	Sign. Level (p)
Depth (D)	92.856	7,68	4	23.214	46.473	.000***
Tillage (O)	9.04	0,75	1	9.04	18.098	.000***
Rotation (S)	1016.734	84,09	1	1016.734	2035.443	.000***
D*O	7.648	0,64	4	1.912	3.828	.010 **
D*S	18.68	1,54	4	4.67	9.349	.000***
O*S	28.607	2,37	1	28.607	57.27	.000***
D*O*S	15.489	1,28	4	3.872	7.752	.000***
Error	19.981	1,65	40	0.5		
Total Sum	1209.036		59			

SPD 5% =1,166

SPD 1% =1,560

SPD 0,1%=2,049

The content of soil moisture in the arable layer in the phase of "tasselling" of maize has values below the wilting moisture - 7.40%, as a result of the higher consumption of the enhanced vegetation of the crop and the loss due to evaporation after inter-row cultivation. The lowest values were reported in the layer 0-10 cm (A_6 – 3.91%) and 10-20 cm (A_6 – 5.7%), (Figure 5b). The lower humidity values are due to the lack of precipitation during the vegetation period and from the vegetation treatments (Figure 1).

Maize yield was reduced by water stress, in the different stages of development, but the culture is very sensitive during the phases of tasseling and detection of the cob.

Bulk density of the soil.

Bulk density is one of the most frequently measured parameters, primarily as an indicator of the presence of soil compaction.

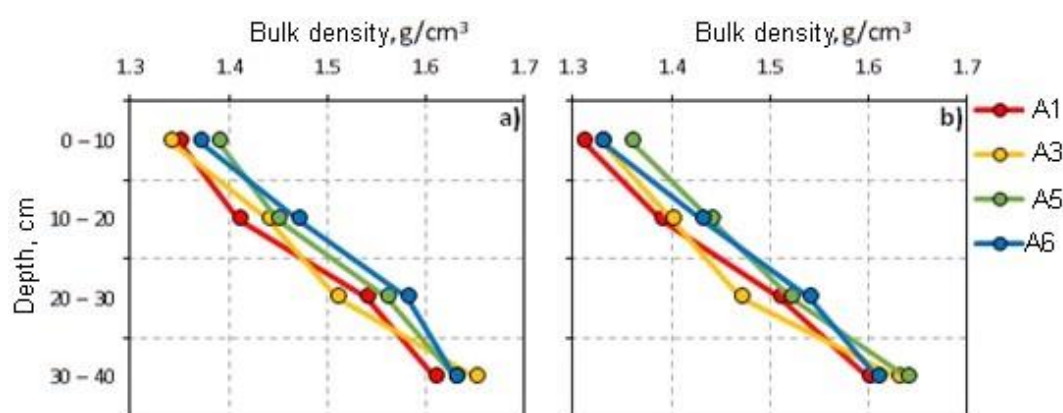


Figure 6. Bulk density of soil in g/cm^3 - maize 2016 a) phase "3-5 leaf"; b) phase "tasselling"

The bulk density of the soil measured in the phase "3-5 leaf" of maize in the first year of the experiment was differentiated by layer. The surface layer has a value between 1.3 g/cm^3 - 1.4 g/cm^3 , then slightly increases in the layer 10-20 cm, increases its values in 20-30 cm (1.51 - 1.59 g/cm^3) and reaches the highest value in the layer 30-40 cm - 1.66 g/cm^3 in A_3 (Figure 6a). The bulk density of the variants with used cover crops was lower compared to the variant without compaction

In the "tasseling" stage of maize, the measured values for soil bulk density remain almost unchanged and show a steady upward trend from the surface to the deepest layer of the soil profile. Although statistically unproven, there are differences between the values of the parameter in the variants with preculture (A_1 and A_3) and the one without preculture (A_5) in the 0-30 cm layer (Figure 6b). This fact shows that compaction of the area with preculture helps to maintain the values of bulk density in a lower range.

The bulk density determined during the barley vegetation is high. In the "tillering" phase, they show an upward trend from the surface to the deepest layers.

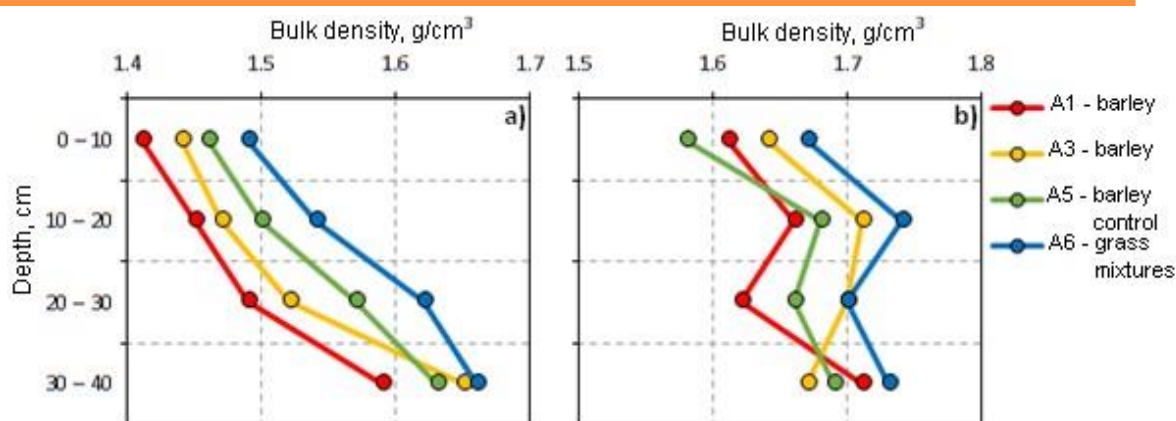


Figure 7. Bulk density of soil in g/cm^3 –barley 2017 a) phase “tillering” b) phase “end of heading: inflorescence fully emerged”

The values are lower in the variants A_1 and A_3 (barley after maize with preculture winter and spring mixtures) in the layer 0-10 and 10-20 cm bulk density is $1.41 - 1.43 \text{ g/cm}^3$ and the layer 20-30 respectively to $1.49 - 1.52 \text{ g/cm}^3$ (Figure 7a). The differences compared to variant A_5 (control) in the layer of 20-30 cm were proved at $p < 1\%$ and $p < 5\%$. Most significant in this crop stage is the influence of crop rotation on the percentage of moisture content in the soil – 47.74% followed by soil depth – 28.60% (Table 5). In stage „end of heading: inflorescence fully emerged “for all studied variants, the obtained data for bulk density are higher than those reported in the „tillering “stage”. In all studied variants of this vegetative stage, the highest obtained values were recorded in 10-20 cm depth and the lowest in the 0-10 cm layer. In the 0-10 cm layer, the lowest value was obtained in variant A_5 and the highest in A_6 . At a depth of 30-40 cm, the lowest value was recorded in variant A_3 and the highest in A_6 (Figure 7b).

Table 5. Dispersion analysis of bulk density – barley “tillering” phase 2017

Source of variation	Sum of Squares	Sum of Sq. %	Value of ch.	Middle Sq.	F-rate	Sign. Level (p)
Depth (D)	0.139	28,60	3	0.046	40.159	.000***
Tillage (O)	0.04	8,23	1	0.04	34.375	.000***
Rotation (S)	0.232	47,74	1	0.232	201.365	.000***
D*O	0.007	1,44	3	0.002	1.986	.136-
D*S	0.014	2,88	3	0.005	4.007	.016**
O*S	0.004	0,82	1	0.004	3.495	.071*
D*O*S	0.013	2,67	3	0.004	3.73	.021**
Error	0.037	7,62	32	0.001		
Total Sum	0.486		47			

SPD 5% =0,052

SPD 1% =0,072

SPD 0,1% =0,093

In the barley “tillering” stage, this trend is also found in variant A_1 , while in A_3 in the arable layer, the bulk density increases to 1.71 g/cm^3 , which is due to the formation of a thick soil crust due to drought. The highest values were reported for the variant with perennial grass

mixture from 1.68 g/cm^3 to 1.74 g/cm^3 . As a general trend showed, lower values are reported in the variants with the growing of the crops in three-field crop rotation.

In the third year of the study, the bulk density determined during maize vegetation was high. The values show an upward trend from the surface to the deepest layers (Figure 8a). The lowest values for the bulk density in the vegetative stage "3-5 leaf" were obtained again in the variants with winter and spring mixtures, as in the layer 10-20 cm the differences compared to the control were proved with a probability of error $p < 1\%$.

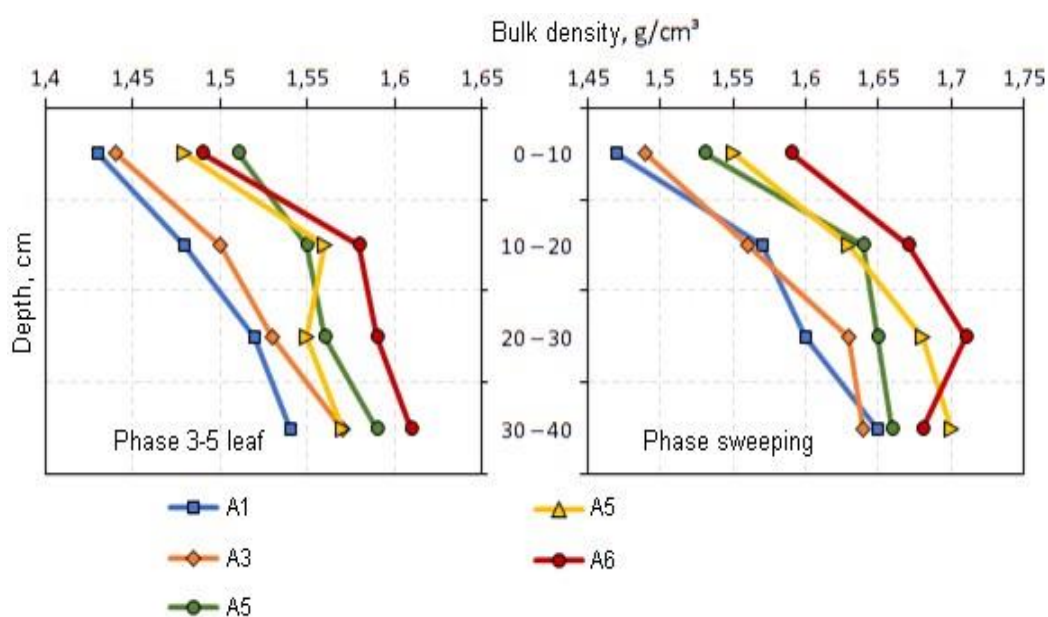


Figure 8. Bulk density of soil in g/cm^3 – maize 2018 a) phase "3-5 leaf"; b) phase "tasselling".

Statistically proven ($p < 0.1\%$) is the difference between the measured bulk density in the layer 0-30 cm between the variant with perennial crops and those with winter mixtures, and the differences reach 0.14 g/cm^3 .

In the „tasseling” crop stage of maize as a result of the deficit of soil moisture, the bulk density in the deeper layers increases significantly. The lowest value for all studied variants was reported in the A_1 (variant with compaction with winter mixture) in 0-10 cm layer. The highest value is the bulk density of the area with the perennial mixture from 1.59 to 1.71 g/cm^3 , as compared to the control (Figure. 8b). There is a proven difference only in the layer 0-10 cm, which is 0.07 g/cm^3 , compared to variant A_1 . There are significant differences in the layer 0-30 cm (Table 6).

From the dispersion analysis of the data, it was established that all the studied factors have an influence, the most significant being the influence of the depth of cultivation, the alternation of the crops, and their interaction. During the study period, the layer 0-20 cm with the largest share of active root mass and the presence of microorganisms are the variants with compaction of crop rotation. As a result of properly conducted agro-technical measures, the bulk density is maintained in values up to the critical limits, despite the lower soil moisture during the growing season. Compaction of the area with pre-crops helps to maintain the bulk density with lower values.

Table 6. Dispersion analysis of bulk density – maize "tasseling" phase 2018

Source of variation	Sum of Squares	Sum. of Sq. %	Value of ch.	Middle Sq.	F-rate	Sign. Level (p)
Depth (D)	0.17	4,96	3	0.057	30.938	.000***
Tillage (O)	0.019	1,67	1	0.019	10.473	.003**
Rotation (S)	0.837	73,68	1	0.837	456.768	.000***
D*O	0.004	0,36	3	0.001	0.812	.497 -
D*S	0.025	2,20	3	0.008	4.538	.009**
O*S	0.009	0,79	1	0.009	4.655	.039*
D*O*S	0.012	1,06	3	0.004	2.218	.105 -
Error	0.059	5,19	32	0.002		
Total Sum	1.136		47			

SPD 5% = 0,074

SPD1% = 0,100

SPD0,1% = 0,132

Soil strength

Soil strength is a parameter that is closely correlated with soil moisture and bulk density. In the Alluvial-meadow (Eutric Fluvisol) in Tsalapitsa the humus horizon is shallow and with low organic content, and the fraction of coarse sand predominates in the soil structure. Therefore, at greater depths, the soil strength is often higher. During the study period the values in the treated layer up to 30 cm are within the optimal range, whereas there is no risk of impeding the penetration and function of the roots of cultivated plants.

When growing maize for the first year in the crop rotation, as a general tendency it was found that the soil resistance was maintained within the limits of the optimal values for the parameter.

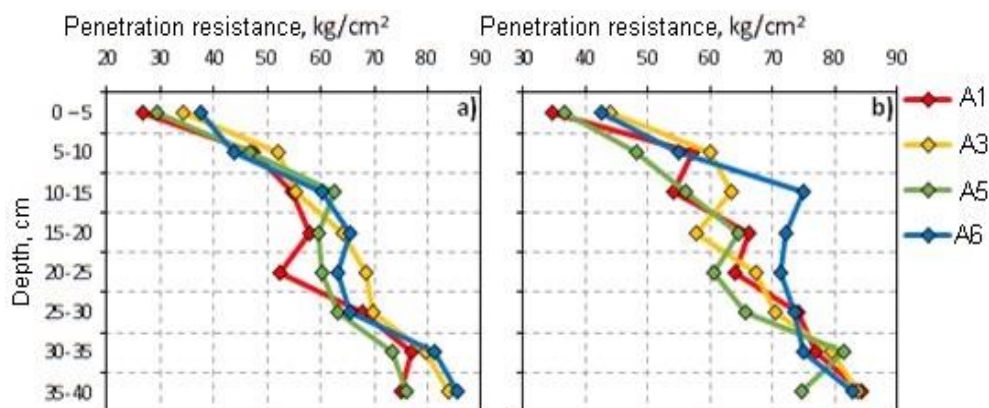


Figure 9. Soil strength in kg/cm^2 - maize 2016 a) phase "3-5 leaf"; b) phase "tasseling".

In the "3-5 leaf" phase, the soil strength from 27.0 to 39.15 kg/cm^2 in the surface layer (0-10 cm) increases in depth and reaches values 2-2.5 times higher than indicated (Figure 9a). In the variant with winter preculture in the 15-25 cm layer, the values are lower.

As the moisture content decreases in the "tasseling" phase, the values increase by about 10.30 kg/cm^2 compared to those reported in the spring. The soil in the layer of 10-40

cm of the variant with perennial grass mixture has the greatest strength. This fact proves the role of tillage as a regulator of its physical condition (Figure 9b). The compaction with precultures in variants A₁ and A₃ has a positive effect on the values of the parameter in the layer 10-20 cm. The soil strength reported in the barley “tillering” phase (second year of the study) ranged from 13.78 kg/cm² to 104.61 kg/cm². The hardness of the soil in the layer of 15-25 cm increased most significantly in all tested variants, probably due to strong soil compaction. At low moisture content, the strength of the soil aggregates and the adhesion forces between them increase significantly. At the end of the vegetation in barley after maize (spring mixtures) the increase of the resistance forces is the most significant – over 120 kg/cm². In the variant barley, after maize compacted with winter mixtures, the reported values of soil strength are the lowest compared to the control and other variants, probably due to the full coverage of the soil surface with plants throughout the year.

During the spring period of the third year of the study in the “3-5 leaf” stage of maize, the reported values for soil strength ranged from 31.78 kg/cm² to 94.61 kg/cm² (Figure 10a). In the treated layer up to 20 cm, the values are within the optimal limits, where there is no risk of impeding the penetration and function of the roots of cultivated plants.

Due to strong soil compaction in the depth 5-10 and 20-25 cm layers, the hardness increases significantly - from 72.40 to 95.08 kg/cm² (A₆). In maize the variant after winter mixtures (A₁), the reported values of soil strength are the lowest compared to the other variants (on average by 20.96 kg/cm²), probably due to the fuller coverage of the soil surface with plants during the period of severe drought. Statistically proven ($p < 1\%$) is the difference in the layer 20-30 cm.

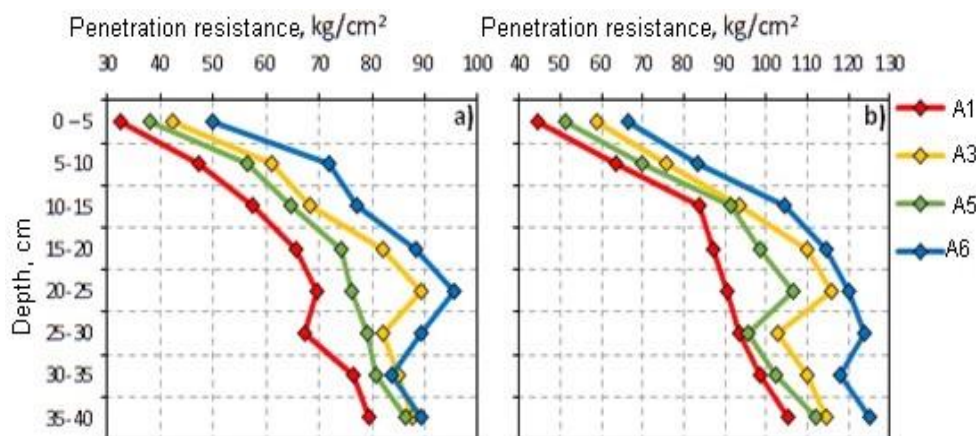


Figure 10. Soil strength in kg/cm² - maize 2018 a) phase 3-5 leaf; b) phase „tasseling“.

In the „tasseling“ phase of maize, there is a differentiation of values depending on the factors tested. The tendency of lower values of the parameter in the variant with winter mixture shows that the coverage of the area during the autumn-winter period has a better effect on maintaining the soil strength with lower values than the stubble (variant A₅ with spring mixture). In the control - A₅ without compacted in a layer of 15-25 cm - 108.40 kg/cm². The strength of Eutric Fluvisol remains with the highest values in the variant with the perennial mixture (A₆), and in a layer of 20-30 cm, it is over 120 kg/cm², i.e. in the layer with the strongest drying (Figure 10b).

Conclusions

From the study was established that the investigated factors affect the general physical state of the soil. The year-round plant cover of the soil surface with the sowing of crops provides the most stable maintenance of the values of the studied physical parameters in the optimal range. The compacting with winter pre-crops the risk of negative influence of climatic factors on the physical characteristic of Eutric Fluvisol is reduced. After the spring mixture, there was an increase in bulk density and soil infiltration resistance, possibly due to the poorer soil condition resulting from late tillage for the following spring crop. As a result of properly conducted agro-technical measures, the bulk density is maintained in values up to the critical limits, despite the lower soil moisture during the growing season. Compaction of the area with intermediate crops helps to maintain the bulk density with lower values. During the research period, the soil strength values in the arable layer up to 30 cm. are within the optimal limits, and there is no risk of hindering the penetration and functioning of the roots of the cultivated plants. The study confirms the role of soil cultivation in improving the studied physical parameters - moisture content, bulk density, and soil strength.

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Influence of Land Use on Spatio-Temporal Variation in Soil Moisture in a Sahel Area of North East Nigeria



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Abstract

Soil moisture plays a great role in physical, chemical and biological activities in the soils. A research was conducted to determine the soil moisture contents across three land use types (grassland (GL), forested area (FR) and cultivated land (CL)) over a period of three months during rainy season in Federal University Gashua, North East of Nigeria. Soil samples were taken from each land use type using soil auger at 0-15 and 15-30cm depths for physico-chemical properties analysis, while core samples were taken fortnightly and after every rainy event for gravimetric soil moisture content (SMC) and bulk density determination. Results showed that the soils across the land uses are sandy loam in texture, high bulk density at GL and CL ($>1.80\text{g cm}^{-3}$) and moderate in FR (1.45g cm^{-3}), very low organic matter content and neutral in pH value. Significantly high SMC was recorded in FR and lower in GL with a high coefficient of variation (43%). Temporally, the SMC varied moderately (35% coefficient of variation) with significant increase after every rainfall event. The high bulk density and very low water retention capacity of the soils of the study area can be enhanced by conservation farming practices and constant addition of organic matter.

Keywords: Gashua, moisture, north east, savanna, soil.

Introduction

Physical, chemical, and biological processes of the soil system are usually influenced by soil moisture content (Brevik et al., 2015). Water contained in the soil is called soil moisture, its presence and movement are key variables for different applications in the fields of agriculture and vegetation growth monitoring, climate system, hydrology and stream flow prediction (Seneviratne et al., 2010; Kumar et al., 2014). Understanding soil water variations under different land use types is critical for agricultural water management and land erosion control (Gao and Shao, 2012; Ziadat and Taimeh, 2013).

Soil moisture is one of the key factors limiting the growth of plants most especially in the arid and semi-arid environment where the crop water requirements in most cases are

beyond the water supply, but even in the humid environment where poor rainfall distribution and water management results in occasional water stresses (Musa and Adeoye, 2010).

Land use change was found also to contribute to the variability of soil moisture, leading to soil deterioration, agricultural productivity decline and land degradation (Biro et al., 2013; Leh et al., 2013; Parras-Alcántara and Lozano-García, 2014). Evaluation of the temporal and spatial variation of soil moisture in numerous land uses is important for vegetation restoration and watershed management (Li et al., 2018). The soil internal factors affecting the spatial and temporal changes of soil moisture were mainly roots, soil texture, and soil organic carbon, and reported that soil clay content was the major factor affecting the spatial distribution of soil water on a semi-arid land (Gao and Shao, 2012). The temporal variation in soil moisture was also driven by meteorological properties like seasonal changes in temperature and evapotranspiration (Jia et al., 2017). In arid and semi-arid regions, the most important limiting factor to sustainable crop production is soil moisture. This valuable resource for sustainable agriculture must be monitored, conserved and managed well. Knowledge of the spatial and temporal distribution of soil moisture and the impact of land use types on its availability is indispensable for correct management strategies. In some tropical regions the availability of reliable data for water retention in respect to soil type, texture and organic matter content is low, it therefore became desirable to analyze the soil so as to estimate its water retention capacity through moisture content determination within the selected land uses for sustainable water management. The study was conducted to determine the soil moisture variation on the selected land use types in Gashua, Yobe State, North East, Nigeria.

Materials and Methods

The study was conducted at Federal University Gashua, Bade Local Government Area of Yobe State, Nigeria. Bade LGA is located between longitudes $12^{\circ} 30'$ and $12^{\circ} 65'N$ and latitudes $10^{\circ} 35'$ and $11^{\circ} 15'E$ (Figure 1). The area is situated in the Sahel savanna agro-ecological zone of Nigeria. It has an area of 809.661 km² with a population of 139,804. The most important vegetation type is that of the Sahel savannah, which consists mostly of open thorny savannah with short trees and grasses (Alhassan et al., 2018).

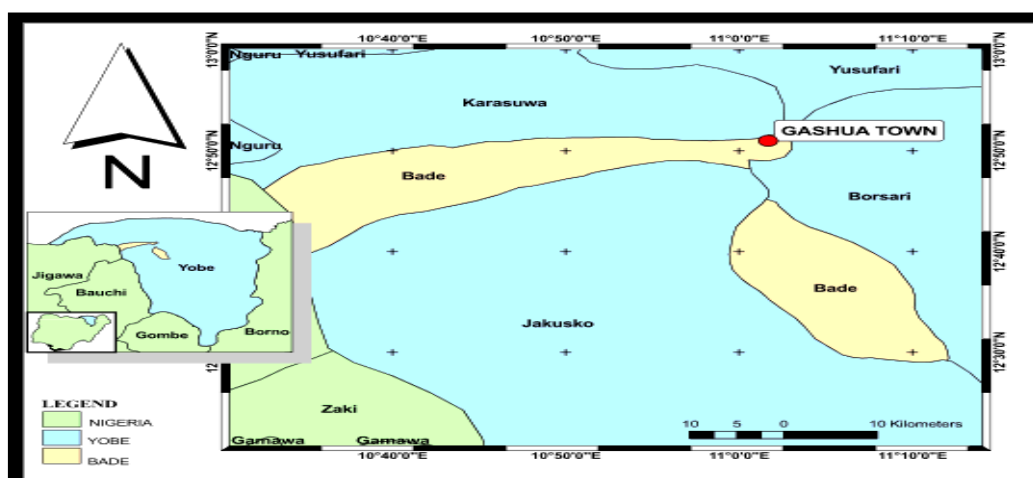


Figure 1. Location map of the study area

Geology and soils of the study area

The area is located within the Chad basin, lithological description consist of continental depositions, which was deposited unconformable over the Precambrian crystalline basement rock (Agada et al., 2020). The soils of Bade LGA showed a dominance of sand particles and most of them belong to the textural class of sandy loam with very low level of most of the essential nutrients (Alhassan et al., 2018).

Climate of the study area

The climate is characterized by high atmospheric temperature and low seasonal rainfall. The mean minimum temperature ranges between 10-12°C usually in December/January, while the mean maximum is about 35-42°C mostly in March to May. The annual average rainfall is about 300-450 mm per annum and is unimodal and lasts from July to October while the dry season starts from late October to May (Alhassan et al., 2020).

Soil sampling techniques

The sampled land use type's locations and coordinates were cultivated land (11°00'90"N, 12°52'57"E), forested area (11°00'95"N, 12°54'56"E) and grass land (11°00'75"N, 12°53'11"E). Three soil samples collected using soil auger from each of the selected land use types at 0-15 and 15-30 cm depths at random. A total of 18 soil samples were then collected from the three land use types. Composite samples were made for each sampling depth thus, arriving at six composite samples which were then package separately in polythene bags according to depth and site for processing and laboratory analysis.

Soil analysis

The samples were air-dried separately, ground using a pestle and mortar, and sieved through a 2 mm sieve for particle size analyses, pH, EC, organic matter and other chemical properties. Particle size distribution was determined by hydrometer method. pH (in water) was determined potentiometrically using pH meter in a 1:2.5 soil: water ratio. Electrical conductivity (EC) was determined from soluble salts in an extracted solution of 1:2.5 soil: water ratio using electric conductivity meter. Organic carbon (OC) was determined by Walkley-Black dichromate wet oxidation method, percent of OM was obtained by multiplying percent soil OC by a factor of 1.724. Total nitrogen content of the soil was analyzed by micro-Kjeldahl method. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1.0M NH₄OAC solution buffered at pH 7.0. Calcium and Magnesium in the filtrate were determined with an Atomic Absorption Spectrophotometer, while K and Na with Flame Photometer. Cation exchange capacity (CEC) was determined by neutral (pH 7.0) NH₄OAc saturation method. Available phosphorus (AP) was determined using after the extraction of the soil samples with 0.5M sodium bicarbonate (NaHCO₃) following the Olsen extraction method (Estefan et al., 2013).

Determination of soil moisture, soil bulk density and soil porosity

Soil samples for soil moisture determination were taken also at 0-15cm and 15-30cm depths using core sampler. Samples were taken fortnightly and two days after every rain to determine the temporal trend and effect of rainfall respectively on soil moisture content under

the selected land use types. Samples were taken from 8th August to 31st October, 2021. The samples were then weighed for moist weight (ww) and placed in an Oven to dry at a temperature of 105°C for 24 hours. The dried samples were then weighed to obtain the dry weight (wd). It is then obtained using the expression in Hillel (2014):

$$SMC (\%) = \frac{ww(g) - wd(g)}{wd(g)} \times 100$$

(Eq.1)

Where: SMC (%) = soil moisture content in percentage, ww = weight of wet soil (g), wd = weight of dry soil (g).

Bulk density was determined on individual samples by dividing the oven-dry weight of the sample by the volume of the soil probe at the respective depth (Reeuwijk, 1992).

$$\text{Bulk density } (\rho_b) = \frac{M_s}{V_t}$$

(Eq.2)

Where: Ms = is the soil oven- dried mass, Vt = volume of the soil core sampler.

Porosity was determined using equation as (one minus the solid volume fraction of a sample (the bulk and particle densities). The ratio of the bulk density (Db), to the particle density (Pp), describes the fraction of the total volume occupied by solids (Hao et al., 2008).

$$TP (\%) = [1 - \left(\frac{\rho_b}{\rho_s}\right)] \times 100$$

(Eq.3)

Where; TP = total porosity, pb = bulk density, ps = particle density (average value of 2.65 g cm⁻³ is used as particle density).

Data analysis

Statistical analyses performed to test the influence of soil moisture on different land use using ANOVA (Analysis of Variance), and comparisons of the difference between mean water content in different land uses were separated by least significant difference (LSD) method using STAR statistical package (STAR, 2013).

Results and Discussion

Effect of land use types on soil physical properties

The soil particle size distribution (PSD) showed that the sand ($p=0.08$) and silt ($p=0.21$) fractions did not significantly differ among land use types (Table 1) and clay ($p=0.04$) was significant different with the land use. The highest overall clay content was recorded under forest land (16.00%) and the lowest in the grass land (13.00%). High clay content in the forested area may be due to the nature of the erosional sediments deposited. The soils of the study area is sandy loam in texture. Similarly, Shehu *et al.* (2015) reported that most of the soils in savanna zone of northern Nigeria had sandy loam texture.

Soil bulk density (BD) ($p=0.0001$) found to be significantly different with the land uses. The soil bulk density was found to be very high in GL with the mean value of 1.85g cm⁻³ which is at par with CL (1.83g cm⁻³) and lower bulk density was recorded in FR with the mean value (1.35g cm⁻³). The lower bulk density found in FR could be due to high organic matter content as the area is covered with trees and grasses, while very high BD in GL and CL it may be due to low organic matter content. Result in GL and CL is very high and could

restrict root penetration as reported in Alhassan *et al.* (2018) that normal range of bulk density for clay is 0.90 to 1.40 g cm⁻³ and a normal range for sand is 1.40 to 1.90 g cm⁻³ with potential root restriction occurring at > 1.40 g cm⁻³ for clay and > 1.60 g cm⁻³ for sand, he also reported mean bulk density value (1.63 g cm⁻³) for soils of Bade LGA in Yobe State, Nigeria. The mean bulk densities recorded are relatively high for crop growth, a desirable bulk density for the soil should be < 1.5 g cm⁻³ and bulk densities greater than 1.6 g cm⁻³ usually restrict root growth (Brady and Weil, 2013)

Porosity ($p=0.0001$) significantly differs within the land use types, the lowest porosity was recorded in GL 30.19% and CL 30.82% and the highest porosity was found in FR 49.06%. Higher porosity found in FR may be due to the high organic matter in the land use, low bulk density and less disturbance. The low porosity recorded in GL and CL it may be due to high bulk density and intensive farming and grazing activities on these lands. This corroborates the work of Abdullah et al. (2018).

Table 1. Effect of Land Use on Soil Physical Properties

Land use	Sand (%)	Silt (%)	Clay (%)	Textural Class	BD (g/cm ³)	Porosity (%)
GL	61.00	26.00	13.00b	SL	1.85a	30.19b
CL	60.00	25.50	14.50ab	SL	1.83a	30.82b
FR	55.50	28.50	16.00a	SL	1.45b	49.06a
SE	2.27	1.67	0.97		0.0186	0.7038
Pr(>F)	0.08	0.21	0.04		0.0000	0.0000
CV%	5.46	8.84	9.48		6.38	11.02

SL = Sandy Loam/ BD=Bulk density/GL=Grass Land/ CL= Cultivated Land/ FR=Forested Area/
SE=Standard Error/ CV=Coefficient of Variance

Effect of land use on soil chemical properties

The results showed that pH ($p=0.19$), EC ($p=0.42$), OC ($p = 0.92$), Na⁺ ($p=0.87$), available phosphorus (AP) ($p=0.18$) where not significantly different with the land use types, while OM ($p= 0.01$), CEC (0.00), N ($p= 0.02$), Mg⁺⁺ ($p= 0.01$), Ca⁺⁺ ($p= 0.00$) and K⁺, ($p=0.02$) concentrations where significantly different within the land uses (Table 2).

The soil pH showed little variability across the land uses with a mean value of 6.98 in GL, 6.76 in CL and 7.10 in FR, the soils are then categorized as neutral as the pH range between 6.51 and 7.5 (QldGov, 2013). The pH values of 6.5 to 7.5 is considered ideal for crop production, therefore, the soil pH values of the study area is considered good for crop production and will not require any amendment (Estefan et al., 2013).

Organic carbon (OC) was not significantly different with the land use types ($p=0.92$). The mean OC recorded are 0.90 g/kg in grass land, 0.93 g/kg in cultivated land and 0.87 g/kg in forested area. The OC content within the soils were considered low according to Esu (1991) rating (<10 g/kg) and is in agreement with Shehu et al. (2018) who reported less than 0.8% OC within the top 30 cm in Southern Guinea Savanna of North Central Nigeria. The soil OC with (CV=17.11%) is moderately varied within the land uses. Bationo and Buerkert (2001) reported 0.4% as a mean concentration of organic carbon within the topsoil of an area in

Sudan zone and 0.2% for the Sahel zone and further opined that the soils in the Sudano-Sahelian zone are inherently low in OC.

Soil organic matter OM ($p=0.01$), were significantly different within the land uses, 0.53g/kg was recorded in grass land, 0.55 g/kg in cultivated land and 0.41 g/kg in forested land. All were found to be very low within the land use types which could be attributed to low vegetative cover as a result of low rainfall that characterizes Sahel savanna areas like Gashua. The study area is characterized by low precipitation and high temperature, this may also contribute to low level of OM as reported to have effect on low of organic matter accumulation (Hamza and Anderson, 2010). Similarly the low organic matter content of the soils in all areas could be attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil (Sharu et al., 2013).

Available phosphorus ($p=0.18$) was found to be not significant within the land uses, 8.75mg kg⁻¹ was recorded in grass land, 8.31mg kg⁻¹ in cultivated land and 9.34 mg kg⁻¹ in forested area also generally rated low (<10 mg/kg) according to Esu (1991). This result falls within the range presented by Alhassan et al. (2020) that available P in the soils of Bade ranged from 7.31- 11.37 mg kg⁻¹. Total nitrogen ($p=0.02$) is significantly different within the land use types. The mean value of 0.04 g/kg was recorded in grass land, 0.08 g/kg in cultivated land and 0.07 g/kg in forested area, indicating overall low level of N according Esu (1991) ratings. The low TN observed in the study area might be due to continues cultivation by farmers over the years and crop removal by uptake.

The CEC ($p=0.00$) was significantly different within the land uses. The mean value of 7.32 cmol(+)/kg was recorded in grass land, 8.11 cmol(+)/kg in cultivated land and 7.74 cmol(+)/kg recorded under forested area. The CEC content is relatively medium as shown that the CEC content between 6 - 12 cmol(+)/kg is median reported by Esu (1991). As the soils were generally low in organic carbon contents, it is probable that the medium CEC obtained could be as a result of the presence of high activity clays and high content of basic cations from parent materials.

The Ca⁺⁺ content ($p=0.01$) was significantly different within the land uses. The mean value recorded in grass land was 6.83 cmol(+)/kg, in cultivated land 6.24 cmol(+)/kg and in forested area 6.11 cmol(+)/kg. The calcium concentration was found to be very high within the land uses. The Mg⁺⁺ contents ($p=0.01$) were found to be significantly different within the land use 1.11 cmol(+)/kg was recorded in grass land, 1.68 cmol(+)/kg in cultivated land and forested area 1.44 cmol(+)/kg. The high level of Mg⁺⁺ might be due to the dominance of Mg bearing minerals in the area. The K⁺ concentration ($p=0.00$) was significantly different within the land use types. Moderately K⁺ content was recorded in grass land (0.24 cmol(+)/kg) and forested area (0.22 cmol(+)/kg) and significantly higher concentration of K⁺ was recorded in cultivated land with the mean value 1.13cmol(+)/kg.

The Na⁺ content of the soil ($p=0.87$) was not significantly different within the land use. Na⁺ recorded within grass land has a mean value 0.15 cmol(+)/kg, while in the cultivated land and forested area were 0.14 cmol(+)/kg each. High soil Na⁺ (>0.3) was also reported by Amalu (1997). The electric conductivity (EC) ($p=0.42$) is not significant different within the land uses. The mean value recorded in grass land was 0.15 (ds/m), 0.10 (ds/m) in cultivated land and 0.15 (ds/m) in forested area.

Table 2. Effect of Land use on Soil Chemical Properties

Land use	pH	EC	OC	OM	CEC	TN	Mg ⁺⁺	Ca ⁺⁺	K ⁺	Na ⁺	AP
		(ds/m)	g/kg	g/kg	cmol(+)/kg	g/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	cmol(+)/kg	mg/kg
GL	6.98	0.15	0.9	0.53a	7.32c	0.04b	1.11c	6.83a	0.24b	0.15	8.75
CL	6.76	0.1	0.89	0.41b	8.11a	0.08a	1.44b	6.11b	1.13a	0.14	8.31
FR	7.1	0.14	0.93	0.55a	7.74b	0.07a	1.68a	6.24b	0.22b	0.14	9.34
SE	0.17	0.02	0.11	0.03	0.05	0.01	0.09	0.18	0.03	0.02	0.51
Pr(>f)	0.19	0.42	0.92	0.01	0	0.02	0.01	0.01	0	0.87	0.18
CV%	3.55	32	17.11	9.79	0.99	26.69	9.87	4.08	10.61	2.05	8.17

GL=Grass Land/ CL= Cultivated Land/ FR=Forested Area/ SE=Standard Error/ CV=Coefficient of Variance

Effect of land uses on soil moisture content

The mean soil moisture content in three land uses are shown in Table 3. The soil moisture content within the land uses were highly significantly different ($p = 0.002$). In general, higher mean moisture content (13.53%) was recorded in forested area (FR) which is at par with 13.01% recorded under cultivated land (CL), while the minimum (10.39%) was found in grassland (GL). The high moisture content recorded under forested area may be due to high organic matter content through shade provided by the trees canopies which may reduce evaporation and decayed leaves and grasses which improve the soil organic matter content and help in soil moisture retention. Also there was high coefficient of variability (CV = 43%) within the land uses as per soil moisture content. This agrees with Yao et al. (2012) who reported that land use was one of the main factors that affected the spatial variations in soil moisture.

Table 3. Mean soil moisture content under Land use types

Land use	Soil Moisture Content (%)
Grassland (GL)	10.39b
Cultivated land (CL)	13.01a
Forested area (FR)	13.53a
SE	0.922
Pr(>F)	0.002
CV (%)	43.00

Effect of sampling depth on soil moisture content (%)

The soil moisture content within the sampled soil depths showed no significant difference ($p=0.495$) between the moisture content (Table 4). This is consistent with Gao and Shao (2012) who observed insignificant variations of soil water at 0–20 cm among various land uses they studied (cropland, shrub land, woodland, and grassland).

Table 4. Effect of sampling depth on soil moisture content

Sampling depth(cm)	Mean
0-15	12.05
15-30	12.58
SE	0.775
Pr(>f)	0.495
CV%	44.28

Effect of temporal variation on soil moisture content

The effect of sampling time (dates) on soil moisture content was presented in Table 5. The result shows that high significant differences exist between the soil moisture content at the different sampling periods. The result showed high moisture content (16.77%) was recorded at the beginning (08/08/2021) and then continue to decline up to the end of August, 2021 (9.52%). The moisture content then increased to 14.55% on 05/09/2021 and decline also to the end of experiment on 31/10/2021 with 5.16%. The sudden increase in soil moisture content after its decline was due to the heavy rainfall experienced on 03/09/2021 and decline to the end of the experiment as no much rainfall was recorded. The increase and decline in soil moisture shows that rainfall has greater influence in soil moisture content, which brings the need for moisture conservation in days without rain.

Table 5. *Effect of sampling date on soil moisture content*

Sampling date	Mean SMC (%)
08-08-21	16.77a
14-08-21	16.42ab
18-08-21	15.23ab
22-08-21	12.49abcd
27-08-21	11.84bcd
31-08-21	9.52cde
05-09-21	14.55ab
19-09-21	13.06abc
03-10-21	12.39abcd
17-10-21	7.99de
31-10-21	5.16e
SE	1.45
Pr(>f)	0.0001
CV%	35.23

Effect rainfall on soil moisture content

There was high significant difference in soil moisture ($p=0.004$) measured after a rainfall event and when there was no rain (Table 6).

Table 6. *Effect of rainfall on soil moisture content*

Rainfall effect	Mean SMC (%)
No rainfall	11.31b
After rainfall	13.51a
SD $\pm$	5.4
Pr(>f)	0.004
CV, %	43.42

Highest soil moisture content was observed (13.51%) after rainfall and (11.31%) when there was no rainfall. This was in agreement with the report that, in arid land, the soil moisture

content often reached its highest value after a heavier rain, and when the rain had stopped for a couple of days, the soil moisture content decreased sharply due to evapotranspiration, absorption by roots or runoff etc. (Fu et al., 2003) further opined that precipitation was the main factor that influenced the temporal patterns in soil moisture (Yao et al., 2003).

Conclusions

This research work was conducted to evaluate soil moisture content of different land use selected in Federal University Gashua, Bade Local Government Area of Yobe State. The land use types are: grass land, cultivated land and forested area. The study showed that the soils of the study area of Federal University Gashua Bade LGA area are Sandy loam, high in bulk density, low porosity, very low in organic matter content. pH was neutral, EC values, total Nitrogen, organic carbon were very low in the soils, while sodium, available P, Ca, Mg, K and CEC ranged between medium to high concentration. The Land uses have shown greater influence on soil moisture retention, which also vary when measured periodically and consistently also been influenced by rainfall.

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Land Suitability Evaluation for Maize Production Among the Soils of Hyuku in Wukari, Taraba State, Nigeria



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Abstract

Suitability evaluation of soils of Hyuku in Wukari Local Government Area of Taraba State, Nigeria was carried out with the view to characterize and evaluate the soils for its suitability for maize production. Two soil units were identified based on their physical, chemical and morphological features using grid method of soil survey. Two profile pits were sunk in each unit, making a total of four pits in all. The soils were deep (80 to 115 cm), well drained with sandy loam surface textures and sandy loam to clay loam subsurface textured. The soil reaction was moderately acidic (5.65 to 6.75) with high base saturation (95.07 to 96.40 %), low organic carbon (0.13 to 0.34 %), low nitrogen (0.17 to 0.67 %), and moderate to low available phosphorus (2.77 to 5.52 ppm). The soil characteristics were matched with the requirement of maize and the overall suitability rating of the soils were obtained using limitation method. Units I and II soils were rated as moderately suitable (S₂) for maize production.

Keywords: land suitability, evaluation, maize production and soil

Introduction

Maize is one of the main staple crops grown in Nigeria. Improving yield and efficiency in resource use is vital to ensuring adequate food security and environmental sustainability. The slight increase in maize production in Nigeria has been attributed to increase in hectares devoted to its cultivation and not optimum yield of each farmland. Recent report of FAOSTAT (2012) has also shown that the cultivation of areas used for maize production (Kaduna state) have declined by about 20 % from the periods of 1991 to 2000 and 2001 to 2010. In addition, the potential yield of maize crop using the improved seedling in Nigeria is not enough compared to that of the developed countries (Oyekale, 2008). Also, very key is the improper land-use resulting to land degradation and decline in agricultural

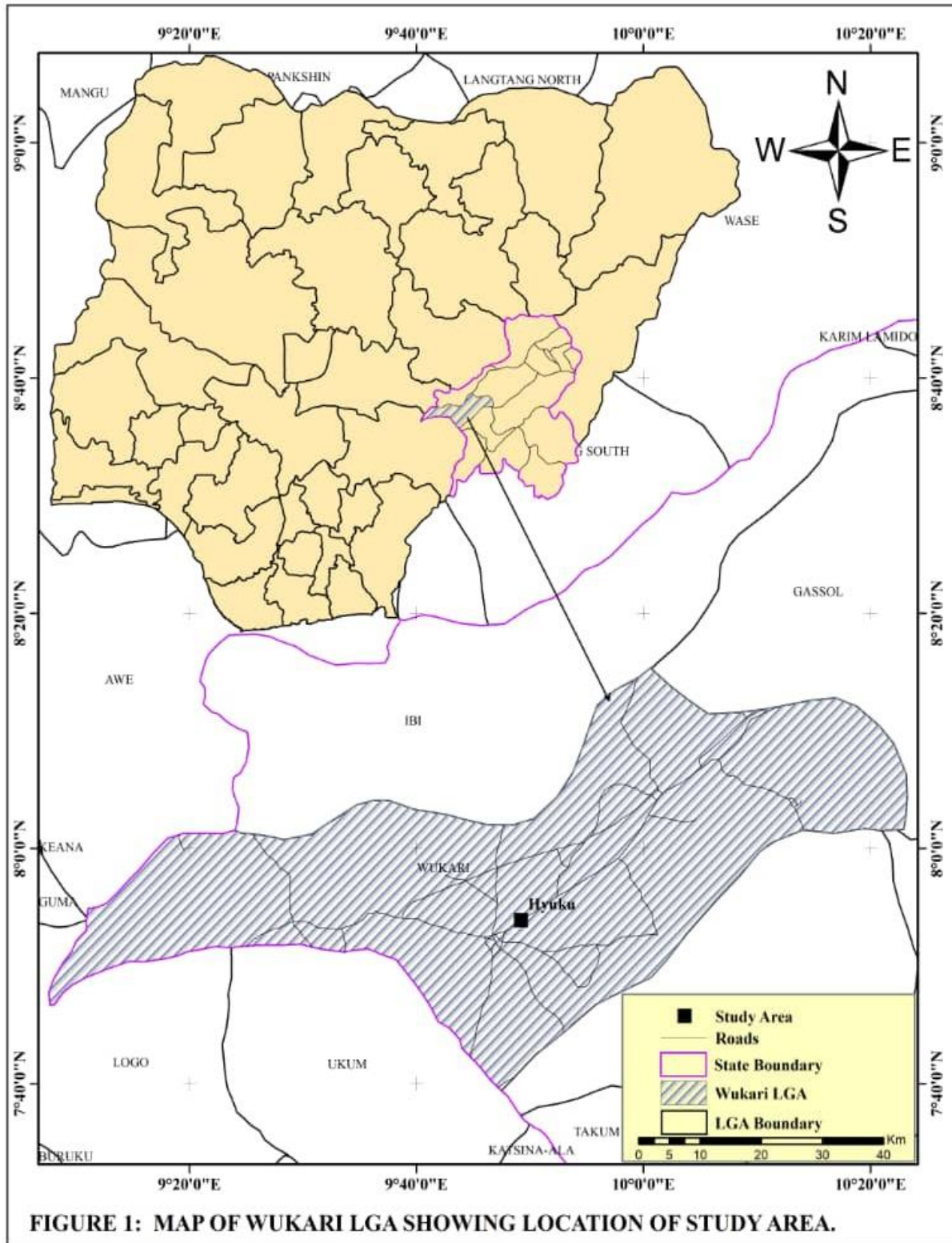
productivity generally with maize inclusive. One of the best ways of soil conservation is the allocation of the soil to its most suitable use. Allocation of the soil/land to its best uses is referred to as Land use planning in which the characteristics of the land are compared or matched with the requirements of particular land use. Land use planning also known as land suitability ensured optimum or even maximum output and at the same time guarantees minimum damage to the land resources.

Land suitability is the fitness of a given type of land for a defined use. Land suitability assessment for agriculture is meant to evaluate the ability of a piece of land to provide optimal ecological requirement of a certain crop variety. That is, assessing the capability of land is enabling optimum crop development and maximum productivity. Thus, evaluation needs a specification of the respective crop requirement and calibrating them with the terrain and soil parameters (Dent and Young, 1981). The identified limiting factors could be managed to suit various crop requirement and improve crop productivity. This is a pre-requisite to productivity maximization in agricultural sector (Pareta and Jain, 2010). Land evaluation provides avenues for sustainable land use since land will be used according to its capability. This therefore, makes it mandatory in this study to carry out land suitability in order to ensure that the selected site is suitable and capable of sustaining long term production of maize.

Materials and Methods

Study Area

The study area is located in Hyuku, Wukari Local Government Area of Taraba State, North East of Nigeria. It lies between latitude 7° 51' to 7° 85'N and longitude 9° 46' to 9° 78' E, of the Greenwich meridian. The entire area is a gently undulating plain, with a mean altitude of 200m above the Sea level. The drainage systems drain northward and serve as tributaries network to the river Benue while Eastward discharge of rivulets and other smaller tributaries from Wukari town drains towards the Donga River, which is a major tributary of River Benue. The mean annual rainfall value ranges from 1000-1500mm. The onset of the raining season is usually around April, while the offset period is October. The mean maximum temperature is being experienced around April at about 40°C while the mean minimum temperature occurs between the period of December and February at about 20°C (NIMET, 2015). The study area is situated over Cretaceous sandstone popularly known as Bima-sandstone. The vegetation consists of grassland interspersed with trees and shrubs. The soils are moderately deep to deep, well-drained to poorly drained, with loamy sand to sandy loam surface over sandy clay loam to sandy clay subsurface (Peng *et al.*, 2006). Land use includes the cultivation of Maize (*Zea mays L.*), Cowpea (*Vigna unguiculata L.* Walp), Groundnut (*Arachis hypogea*), Rice (*Oryza sativa*), Guinea corn (*Sorghum bicolor*), Beniseed (*Sesamum indicum*), Bambara nut (*Voadenzia subterranea*), Yam (*Dioscorea spp*), Okra (*Albemoschus esculentus*), as well as Cashew (*Anacardium occidentale*) and Mango (*Mangifera indica*) as well as Oil palm (*Elaeis guineensis*) plantations. Grassland areas support animal grazing activities.



Field and Laboratory Studies

The area was soil surveyed using the grid method. Auger point investigations were carried out at 100 m intervals along traverses cut at 100 m apart on the baseline. Based on these investigations, two soil units were identified and two profile pits were sunk in each. The

pits were described according to the guideline for soil profile description (SSS, 2014) and the samples were collected and taken to laboratory for physical and chemical analysis. The air dried, crushed and sieved ($d < 2\text{mm}$) samples were analyzed for particle size distribution (PSD), pH, organic carbon, CEC, exchangeable bases (Ca, Mg, K and Na), total N, available P, and base saturation.

PSD was determined by Bouyoucos hydrometer method (Day, 1965). Soil pH was determined by electrometric methods as described by IITA (2015). Walkley and Black method as described by Nelson and Sommers (1982) was employed for organic matter content determination. Total N was determined using the modified macro-kjeldahl method as described by IITA (2015). Bray No.1 method was used for extractable P. For exchangeable bases, Ca and Mg were determined by AAS while K and Na were done by flame photometer. CEC was determined by IITA (2015) procedures while base saturation was calculated by dividing TEB by ECEC and multiplying by 100%.

Land Suitability Evaluation (LSE)

The FAO framework for soil suitability classification was used for the study, according to Sys (1985). The suitability of the soils was evaluated by a direct method where the established soil land characteristics (Sys, 1985) were cross-matched with the soil land characteristics obtained from the study. The outcome was cross-matched with the suitability class rates and agricultural uses, according to Ezeaku (2011).

Results and Discussion

Soil Morphological Characteristics

The soil morphological characteristics examined in the study area include; the soil colour, texture, structure, depth and consistence (Table 1). The soils were predominantly dark reddish brown (2.5 YR 2.5/6), reddish brown (2.5 YR 5/4) and light reddish brown (2.5 YR6/3) colours (moist) in their A and Ap horizons of all the profiles. This could be attributed to the presence of relatively high organic matter which is the main colouring agent on surface soils (Ufot, 2012). In the subsurface horizons of the profiles, the presence of light reddish brown (2.5 Y 6/4 moist) and reddish colour is an indication of complete organic matter decomposition (oxygen rich soil) and seasonal fluctuation of ground water table resulting in the reddish yellow (5YR 7/6) mottles observed. Such mottles were mainly confined to root channels because of the oxidizing effect of oxygen, which enters the channels as soon as the water table receded. The soils were deep ranging from 80 to 110 cm. They are generally well drained with sandy loam surface textures while the sub-surfaces varied from sandy loam to loam to silty clay loam to loam. The textures of these soils reflected the parent rocks from which they are formed, the rate and the nature of some weathering processes (Ahukaemere *et al.*, 2016; Idoga and Azagaku, 2005). The soil structures were well developed being moderate medium crumb to moderate medium subangular blocky at the surface while the subsurface was moderate medium subangular blocky to strong medium crumb. The structures are functions of organic matter content of the soil (Akinyemi and Vivian, 2001).

Physical and Chemical Properties of the Study Area

The physical properties of the soils of the study site are shown in Tables 2. For all the profiles, sand fraction ranged from 31.2 to 75.4% in surface and subsurface soils respectively. Similarly, silt fraction varied from 20.4 to 38.8% respectively; and a range of 4.0 to 38.0% for clay fraction at the surface and subsurface respectively were observed. The texture of the soils studied was sandy loam at the surface while subsurface horizons varied from sandy loam to clay loam.

The chemical properties of the soils are shown in Table 2. The overall results show that the soils were moderately acidic with pH ranging from 5.65 to 6.75. Organic carbon varied from 0.04 to 0.34 while that of total nitrogen varied from 0.17 to 0.75%. Available phosphorus content ranged from 2.65 to 5.52 mg kg⁻¹. The organic carbon together with total nitrogen and the phosphorus were rated low. Generally, these may be attributed to release from plant tissues, gaseous loss, surface runoffs, leaching, climatic factors, vegetation, human activities and initial soil pH. Loss of N through denitrification and volatilization may also contribute to the low level of N in the wetland (Brady and Ray, 2014). The exchangeable bases were low as a result of the nature of the underlying parent materials, intensity of weathering, leaching, low activity clay, low O.M, erosion and lateral translocation of bases. Ca was the most dominant cations with values ranging between 4.42 and 4.6 cmolkg⁻¹ in the exchange complex. This may be linked to the occurrence of exchange sites which have specific affinity to Ca (Idoga, 1985) or may be due to the fact that Ca is least easily lost from exchange site or has high displacement ability over other cation exchange reaction. The Mg values varied between 0.66 and 0.93 cmolKg⁻¹ while that of K and Na varied from 0.24 to 0.31cmolKg⁻¹ 0.76 to 0.94cmolkg⁻¹ respectively. These values confirmed the predominance of Ca over Mg, K and Na as observed by Idoga, 1985, and Ogunkunle, 1989. CEC content varied between 6.62 and 6.80 cmolkg⁻¹ and were rated low. The CEC of the soils were low to medium with values ranging between 3.75 and 8.34cmolkg⁻¹. The low CEC values may be attributed to the nature of clay minerals (kaolinite) and low organic carbon level of the soils. The percentage base saturation values were very high (95.07% to 96.69%). The high base saturation could probably have associated with the presence of weathered minerals which release nutrients into the soil and their alluvial nature (Table 2).

Suitability Rating for Maize Production

Land suitability assessment for agriculture is meant to evaluate the ability of a piece of land to provide optimal ecological requirement of a certain crop variety. That is, assessing the capability of land is enabling optimum crop development and maximum productivity. Thus, evaluation needs a specification of the respective crop requirement and calibrating them with the terrain and soil parameters (Dent and Young, 1981). The identified limiting factors could be managed to suit various crop requirement and improve crop productivity. This is a pre-requisite to productivity maximization in agricultural sector (Asadu and Ezike, 2017). Land evaluation provides avenues for sustainable land use since land will be used according to its capability. This therefore, makes it mandatory to carry out land suitability in order to ensure that the selected site is suitable and capable of sustaining long term production of crops with maize inclusive.

Table 1.Morphological Properties of the Soils of Hyuku

Horizo n	Depth (cm)	Color (moist)	Mottles	Mottle detail	Texture	Structure	Consistence	Inclusion	Boundary
Unit 1 Profile 1:									
Ap	0-18	2.5YR ^{2.5} / ₃ DRB	-	-	SL	2MCR	SSW	Few Medium Roots	ds
AB t ₁	18-30	2.5YR ⁵ / ₄ RB	-	-	SL	2MSBK	SSW	Few Fine Roots	ds
B t ₂	30-45	2.5YR ⁶ / ₄ LRB	-	-	SL	2MSBK	SSW	Few Fine Roots	ds
Bt ₃	45-80	2.5YR ⁵ / ₆ R	-	-	CL	2MSBK	VSW	Few Fine Roots/hard coherent rock at 80cm	-
Unit 1 Profile 2:									
Ap	0-21	10YR4/6DYD	-	-	SL	2MSBK	SSW	Many coarse roots	ds
AB t ₁	21-34	5YR6/6RY	-	-	SL	2MSBK	SSW	Many coarse roots	ds
B t ₂	34-40	7.5YR6/4LB	-	-	SL	2MSBK	SSW	Common medium roots	gs
Bt ₃	40-90	2.5YR5/2GB	-	-	CL	3CCR	VSW	Few medium roots	-
Unit 2 Profile 1:									
Ap	0-22	2.5YR 3/3DRB	-	-	SL	2MSBK	SSW	Medium Common Roots	ds
AB t ₁	22-37	2.5YR 6/3LRB	-	-	SL	2MSBK	SSW	Few fine roots	ds
Bt ₂	37-55	2.5YR 6/3LRB	-	-	SL	2MSBK	SSW	Few fine roots	gs
Bt ₃	55-89	2.5YR 7/6LRB	-	-	SL	2MSBK	SSW	Few Fine Roots	ds
B t ₄	89-110	2.5YR 6/8LRB	-	-	SL	2MSBK	SSW	Few Fine Roots	-
Unit 2 Profile 2:									
Ap	0-20	7.5YR6/4LB	-	-	SL	2MSBK	SSW	Many medium roots	ds
AB t ₁	20-38	5YR6/6RY	5YR 7/6	M2P	SL	2MSBK	SSW	Common fine roots	ds
Bt ₂	38-60	10YR4/6DYD	-	-	SL	2MSBK	SSW	Few fine roots	ds
Bt ₃	60-90	2.5YR5/2GB	-	-	SL	2MSBK	SSW	Few fine roots	ds
B t ₄	90-115	2.5YR5/4RB	-	-	SL	2MSBK	SSW	Few fine roots	-

Mottling Details: M3P=Many coarse prominent

Texture: SL= Sandy loam, CL= Clay loam

Structure: 3CCR = Strong coarse crumb, 2MCR = Moderate medium subangular blocky

Consistence: SSW = Strongly sticky wet, VSW = Very sticky wet, VPW = Very sticky wet, SW = Sticky wet, NSW = Non-sticky wet, Npw = Non-plastic wet

Boundary: ds = diffuse smooth, gs = gradual smooth

Colour: DB=Dark brown, GB= Grayish Brown, RY= Reddish Yellow, DRB = Dark Reddish Brown, RB = Reddish Brown, DYB= Dark Yellowish Brown, LRB = Light Reddish Brown, LB = Light Brown, R = Red

Table 2. Physical and Chemical Properties of Soils of Hyuku

Horizon	Depth (cm)	Sand → (%)	Silt → (%)	Clay ←	Texture	pH (H ₂ O)	O.C (%)	TN (%)	AP (mgkg ⁻¹)	Ca	Mg	K	Na → (cmolk ⁻¹)	TEB	EA	ECEC	BS (%)
Unit 1 Profile 1:																	
Ap	0-18	73.2	22.8	4.0	SL	6.75	0.23	0.44	2.77	4.60	0.66	0.31	0.93	6.50	0.15	6.80	95.59
AB t ₁	18-30	63.2	28.8	8.0	SL	6.66	0.15	0.45	5.52	4.57	0.68	0.28	0.84	6.37	0.17	6.70	95.07
B t ₂	30-45	61.2	28.8	10.0	SL	5.85	0.11	0.67	5.12	4.61	0.69	0.26	0.78	6.34	0.22	6.80	93.24
Bt ₃	45-80	31.2	30.8	38.0	CL	5.92	0.08	0.45	3.60	4.58	0.67	0.26	0.77	6.28	0.32	6.67	94.15
Unit 1 Profile 2:																	
Ap	0-21	75.4	20.8	3.8	SL	6.56	0.34	0.52	2.65	4.59	0.67	0.30	0.91	6.47	0.16	6.77	95.57
AB t ₁	21-34	65.4	25.4	9.2	SL	6.47	0.26	0.53	4.42	4.56	0.69	0.27	0.82	6.34	0.17	6.71	94.49
B t ₂	34-40	65.8	22.2	12.0	SL	5.66	0.22	0.75	4.30	4.60	0.70	0.25	0.76	6.31	0.22	6.76	93.34
Bt ₃	40-90	52.2	23.8	24.0	CL	5.73	0.19	0.53	4.60	4.58	0.67	0.26	0.74	6.25	0.32	6.62	94.41
Unit 2 Profile 1:																	
Ap	0-22	59.2	34.8	6.0	SL	5.85	0.11	0.45	4.92	4.54	0.81	0.28	0.82	6.45	0.16	6.78	95.13
AB t ₁	22-37	57.2	32.8	10.0	SL	5.75	0.26	0.56	5.46	4.56	0.80	0.28	0.81	6.45	0.14	6.76	95.41
Bt ₂	37-55	47.2	38.8	14.0	SL	5.70	0.15	0.34	2.81	4.54	0.81	0.28	0.79	6.42	0.17	6.70	95.82
Bt ₃	55-89	55.6	26.5	18.0	SL	5.65	0.34	0.17	3.97	4.57	0.77	0.28	0.80	6.39	0.25	6.68	95.66
B t ₄	89-110	60.6	20.4	19.0	SL	5.70	0.04	0.39	4.78	4.61	0.79	0.26	0.76	6.42	0.29	6.66	96.40
Unit 2 Profile 1:																	
Ap	0-20	60.7	34.2	5.1	SL	5.64	0.32	0.45	4.90	4.42	0.93	0.25	0.78	6.38	0.18	6.67	95.65
AB t ₁	20-38	56.8	33.0	10.2	SL	5.82	0.24	0.58	5.44	4.64	0.72	0.29	0.79	6.44	0.15	6.72	95.83
Bt ₂	38-60	52.2	34.0	13.8	SL	5.80	0.17	0.32	2.70	4.65	0.82	0.27	0.80	6.54	0.80	6.80	96.18
Bt ₃	60-90	51.5	31.5	17.0	SL	5.74	0.24	0.27	3.88	4.56	0.78	0.26	0.80	6.40	0.34	6.70	95.52
B t ₄	90-115	48.4	30.2	21.4	SL	5.62	0.13	0.28	4.80	4.52	0.88	0.24	0.79	6.43	0.33	6.65	96.69

N = Nitrogen; AP = Available phosphorus; K = Potassium; Na = Sodium; Ca = Calcium; Mg = Magnesium

The suitability rating of Hyuku soils were carried out by comparing the qualities of the soil with the requirements of maize. The chemical characteristics of the soils such as pH, OC, CEC, exchangeable bases, available P and total N (Table 2) were found to be either conducive to maize production or can be amended by individual farmers and therefore cannot be considered to be permanent limitations.

Table 3. Land Use Requirement for Maize

Land Quality and Characteristics		100-95 S1	94-85 S2	84-40 S3	39-20 N1	19-0 N2
Climate (c):						
Annual rainfall (mm)		850-1250	850-750	750-600	600-500	-
Length of dry season (days)	Mean annual	150-220	1250-1600	1600-	>1800	<90
		22-26	130-150	1800	90-110	>36
max temp. ($^{\circ}$ C)			22-18	110-130	36-30	
Relative humidity (%)		42-50	50-80	18-16 >32 >80	-	-
Topography (t):						
Slope (%)		0-2	2-4	4-8	8-16	
		0-4	4-8	8-16	16-30	>30
Wetness (w):						
Flooding		F0	M0	F1	Aeric	Poor
Drainage		Good	Moderate	Poor	Poor	Drainable
Soil physical Characteristics (s):						
Texture/Structure		CL, L	SL, LS	LCS	CS, S	S
Coarse fragments (%) 0-10 cm		<3	3-15	15-35	35-55	-
Fertility (f):						
CEC (cmolkg ⁻¹ clay)		>24	16-24	<16(-)	16(+)	-
Base saturation (%)		>50	35-50	20-35	<20	-
pH		5.5-7.0	5.5-7.0	5.0-8.0	5.0-8.0	
OC (%) 0-15cm		>2	1.2-2	0.8-1.2	<0.8	-
Av. P (mgkg ⁻¹)		>22	13-22	7-13	3-7	<3
Total N (%)		>0.15	0.10-0.15	0.08-0.10	0.04-0.08	<0.08
Extr. K (cmolkg ⁻¹)		>0.5	0.3-0.5	0.2-0.3	0.1-0.2	<0.1

Key: F0=No Flooding; F1=Seasonal Flooding; CL=Clay Loam; SL=Sandy Loam; LS=Loamy Sand;

SCL=Sandy Clay Loam; S=Sand.

Source: Modified from Sys (1985)

Soil depth, drainage, slope, porosity, texture, structure and soil fertility status are important physical and chemical characteristics that influence maize growth, development and yield. The climatic condition of the area (temperature and rainfall) were highly suitable (S1) and favorable for maize production as values were higher than 640 mm and little above 28 $^{\circ}$ C (FAO, 2007). The textural class was found to be highly suitable (S1) for maize cultivation across the soil units. The soils were well drained, free from flooding and were therefore highly suitable (S1) for maize production. The organic matter content and CEC

were low and so rated marginally suitable (S3) for maize cultivation. Total nitrogen was low to moderately high and therefore rated moderately suitable (S2) for maize. Generally, the aggregate suitability class of the soils suggested that they were moderately suitable (S2) for maize production (Table 3 & 4).

Table 4. Suitability Class Scores of the Profiles in the Study Area for Maize

Land Quality and Characteristics	Profile I	Profile II	Profile III	Profile IV
Climate (c):				
Annual rainfall (mm)	S1(95)	S1(95)	S1(95)	S1(95)
Length of dry season (days)			S1(100)	
Mean annual max temp. ($^{\circ}$ C)	S1(100)	S1(100)	S3(40)	S1(100)
Relative humidity (%)	S3(40)	S3(40)		S3(40)
Topography (t):				
Slope (%)	S1(100)	S1(95)	S2(85)	S2(85)
Wetness (w):				
Flooding				
Drainage	S1(100)	S1(95)	S2(85)	S3(40)
Soil physical Characteristics (s):				
Texture/Structure				
	S1(95)	S1(95)	S2(85)	S2(85)
Fertility (f):				
ECEC (cmolkg ⁻¹ clay)	S3(40)	S3(40)	S3(40)	S3(39)
Base saturation (%)	S1(100)	S1(100)	S1(100)	S1(100)
pH	S2(85)	S2(85)	S2(85)	S2(85)
OC (%) 0-15cm	N1(20)	N1(20)	N1(20)	N1(20)
Av. P (mgkg ⁻¹)	N1(20)	N1(20)	N1(20)	N1(20)
Total N (%)	S1(95)	S1(95)	N1(20)	N1(20)
Extr. K (cmolkg ⁻¹)	S3(84)	S3(40)	S3(84)	S3(84)
Mean value	74	63	66	63
Aggregate suitability class	S2	S2	S2	S2
Limiting Characteristics	d,n	k,n	n	d,n
Aggregate suitability class scores				
100-75 = S1, 74-50 = S2, 49-25 = S3, 24-0 = N1				

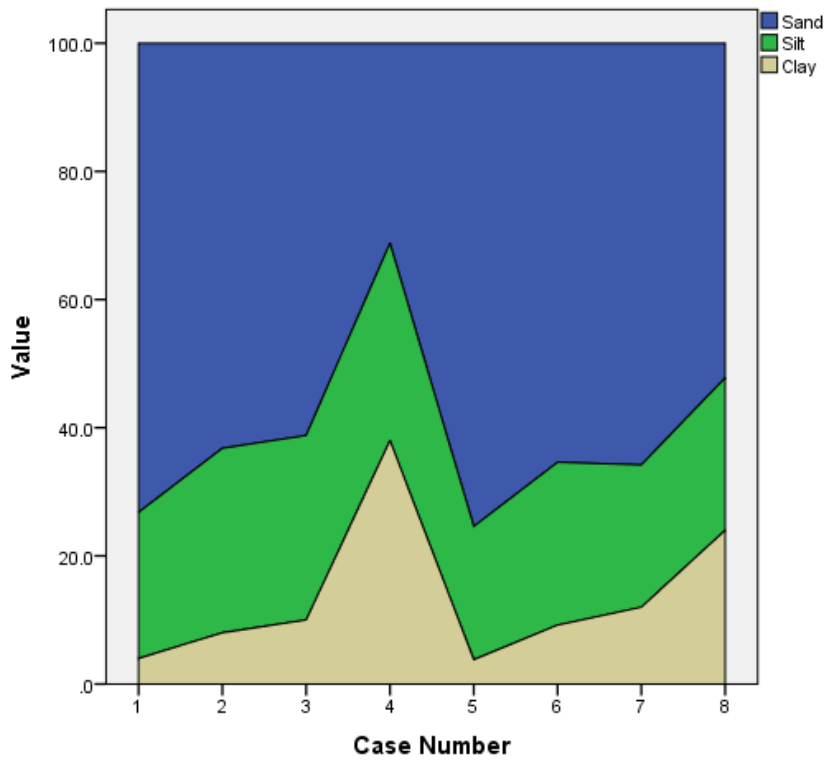


Figure 2. Interaction of Particle Size Distribution (PSD) of the Soils in Unit 1

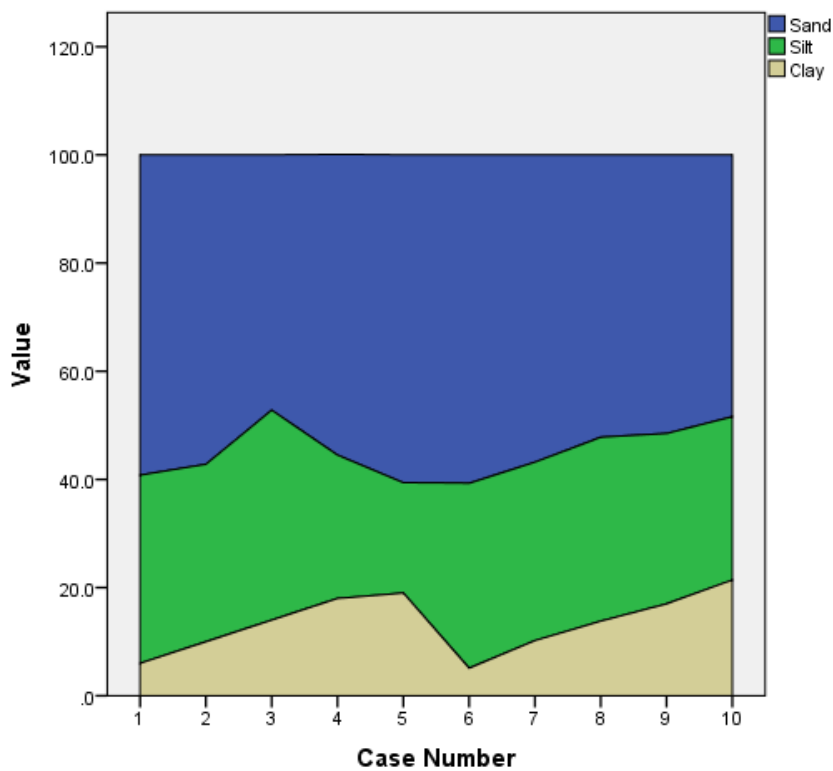


Figure 3. Interaction of Particle Size Distribution (PSD) of the Soils in Unit 2

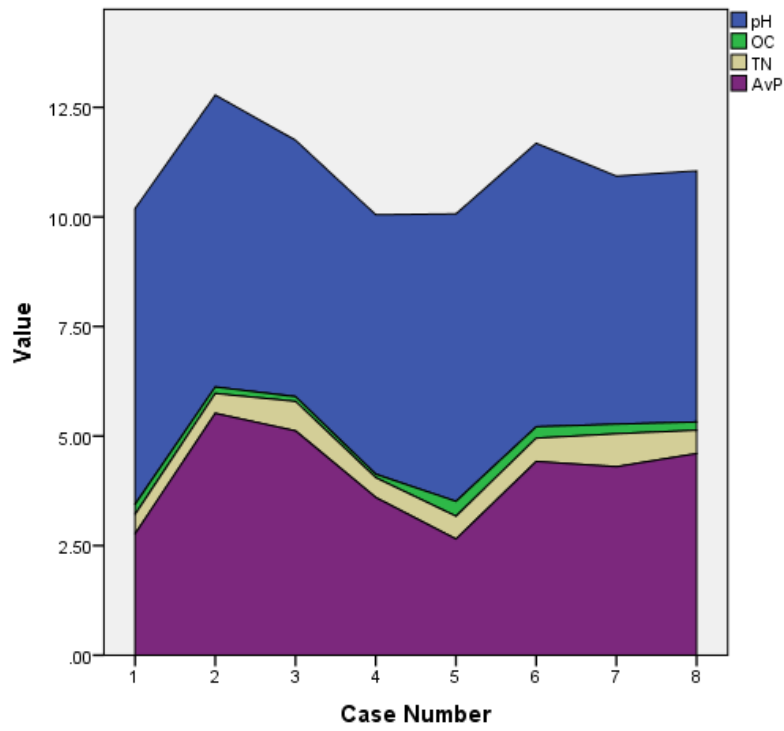


Figure 4. Interaction of pH, OC, TN and Av. P of the Soils in Unit 1

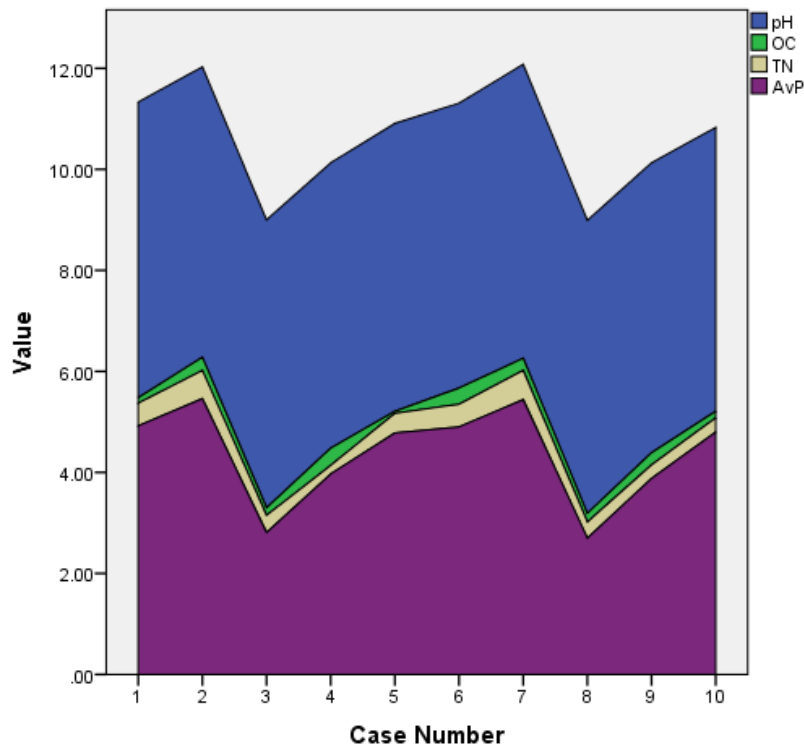


Figure 5. Interaction of pH, OC, TN and Av. P of the Soils in Unit 2

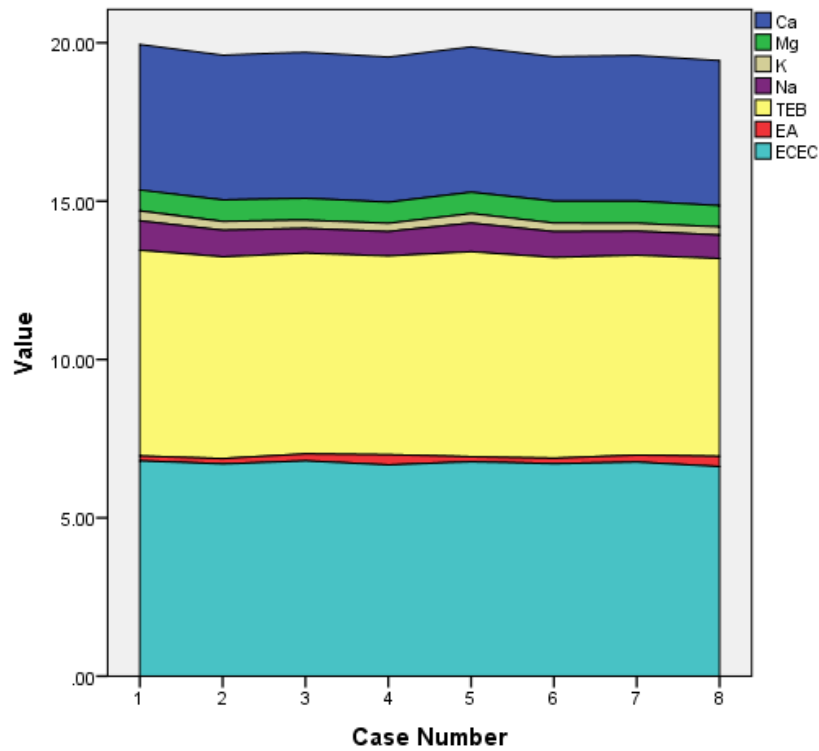


Figure 6. *Interaction of Exchangeable Cations of the Soils in Unit 1*

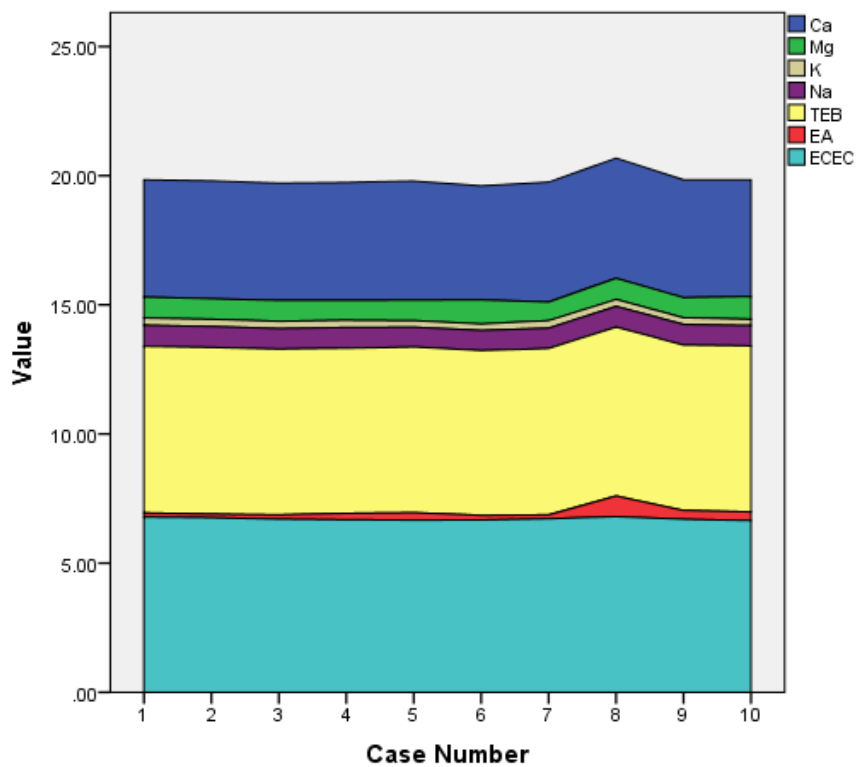


Figure 7. *Interaction of Exchangeable Cations of the Soils in Unit 2*

Conclusion

Selected soils of Hyuku were studied with the aim to characterize and evaluate the soils for its suitability for maize production. Two major soil units were identified in the area.

The soils were deep, well drained and had sandy loam to clay loam texture. They were generally moderately acidic in reaction with pH values ranged between 5.65 and 6.75. This pH range is safe for any sustainable maize production. They also have high base saturation, low value of available P, organic carbon, total nitrogen, and exchangeable cations meaning that they have high potentials to respond positively to any addition/application of fertilizer be it organic or inorganic. Based on the physical and chemical properties of the soils, they were rated as moderately suitable (S2) for maize production.

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Primary Nutrients Status of Three Vermicomposts Produced in a Nigerian Sahel Region

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Abstract

A pot experiment was conducted at the soil and water laboratory of Federal University Gashua Nigeria, to assess the reaction and primary nutrients – NPK, and Organic Carbon (OC) status of three white grub-produced Vermicompost using different ingredients (Municipal Waste – M_w , Typha Grass – T_p , and Municipal Waste + Typha Grass – M_wT_0). Laid on a Completely Randomized Design (CRD), the number of live worms, worms' weight, Vermicompost weight, and worms' mortality percentage as production indices were recorded and statistically analyzed upon Vermicompost maturity. Matured Vermicompost Reaction (pH and EC) and Primary nutrients (NPK), and OC were determined in another laboratory upon taking the respective compost samples as Soil health Indices. The result of the analysis showed that M_w has the highest Nitrogen (%) = 1.60, the highest available Phosphorus = 0.47 mgKg⁻¹, and the highest Exchangeable Potassium = 720 mgKg⁻¹, it also presented a mildly acidic reaction (pH=6.8), with the highest percentage of OC (2.80%) and the lowest basic salts EC = 0.35 dS/m. In terms of earlier determined live worm percentage, live worm weight, Vermicompost weight, and worm mortality rate, the highest findings are M_w = 64.5 %, M_w = 40 grams, M_w = 301 grams, and T_p = 66.9 % respectively. In conclusion, M_w Vermicompost proves to be the best, taking into consideration its better indices. As the premier of its kind in the study area, among other recommendations, we encourage setting this study as a pilot, and

the conduct of more studies on the efficiency of Vermicompost on soil health and crop production in the study area.

Keywords: vermicompost, vermicompost production, primary nutrients, sahel savannah, soil health

Introduction

Vermicomposting is the decomposition of organic residues in an aerobic environment by exploiting the optimum biological activity of earthworms and microorganisms (Garg and Gupta, 2009). Studies on the production of important vegetable crops like tomatoes (*Lycopersicon esculentum*), and eggplant (*Solanum melongena*) using Vermicompost have yielded very good results in Asia (Adhikary, 2012; Ashiwar & Hussain, 2015). Similarly, the overall productivity of many classes of crops was significantly boosted by Vermicompost applied at reasonable amounts per unit area (Adhikary, 2012). Positive findings after the use of Vermicompost as a source of organic manure in supplementing and/or substituting chemical fertilizers lead to it becoming popular among farmers around the world (Joshi *et al.*, 2015). Application of Vermicompost was reported in several literature to enhance most inherent biogeochemical aspects of crop production (Sinha *et al.*, 2009; Ashiwar & Hussain, 2015; Dhanalakshmi *et al.*, 2014; Joshi *et al.*, 2015), as well as its economy (Lim *et al.*, 2015). A Study also suggested that Vermicompost enhances the formation of humic acid and plant growth-promoting bacteria, which is a plus for soil health and sustainable agriculture especially in the tropics (Laufer and Tomlinson, 2013).

Vermicast, a cocoon compound produced during Vermicomposting, produced a higher percentage of the protein and carbohydrate contents as compared to chemical fertilizer in the study of Adhikary (2012). Vermicast was established to be the active constituent, and its action was believed to produced higher garden pea pods per plant, higher green grain weight per plant, and higher green pod yield per hectare as compared to chemical fertilizer, and the overall vegetable production (Adhikary, 2012; Ahirwar & Hussain, 2015).

Recently, Organic farming inputs have been adopted by farmers to boost soil fertility, OC content and the general health of arable soils (Lim *et al.*, 2015). However, the knowledge of deliberate Vermicomposting is among the limiting techniques in agricultural production to the farmers, especially in the Sahel Region of Nigeria. Also, evident is the fact that, chemically synthesized inorganic fertilizers pose economic, health, and degradative risks in the long run (Adugna & Abegaz, 2015).

Located in the Sahel Savannah Agro-ecological zone, in the northern parts of Yobe State of North Eastern Nigeria, Gashua is a predominantly farming and fishing community. Despite its unfavorable climatic condition and low annual rainfall (500 to 1000mm) (FDALR, 1990), Gashua soil is fertile and suitable for cultivation of cereal, tubers, fruits, and vegetable (Alhassan *et al.*, 2018). The soil, however, was reported to have low OC content, a crucial site for ion exchange and buffering (Sani *et al.*, 2019).

In the Nigerian Sahel, with inorganic fertilizers being costly, sometimes scarce, and elsewhere regarded as a security threat, subsistent farmers find it economically impossible to apply enough for good growth (Alhassan *et al.*, 2018). These Farmers depend largely on locally sourced organic fertilizers on one hand (Makinde *et al.*, 2010; Sani *et al.*, 2023). On

the other hand, a huge amount of waste in the form of Municipal Waste (M_W), Farm yard Manure (FYM), and numerous indigenous and exotic grasses that colonize farmlands and waterways such as Typha species, are generated and heaped on dump sites, posing potential environmental pollution and hazard (Agboola and Omuati, 1982). Incorporating these waste materials into the soil for crop production would serve as a source of organic farming inputs to build up an organic matter layer that is needed for a steady supply of nutrients in tropical soils (Agboola and Omuati, 1982; Noma and Sani, 2008), as well, a measure for pollution and bio-degradable waste control.

The potential of Vermicomposting to turn municipal, waterways, and on-farm waste materials into an important farming input makes it an attractive proposition. Vermicomposting offers benefits such as enhanced soil fertility and soil health that engender increased agricultural productivity, improved soil biodiversity, reduced ecological risks, and a better environment (Adhikary, 2012; Sinha et al., 2009; Ashiwar & Hussain, 2015; Barik et al., 2011; Dhanalakshmi et al., 2014; Dominquez & Edwards, 2004; Garg & Gupta, 2009; Joshi et al., 2015; Lim et al., 2015; Mistry, 2015; Sinha et al., 2010). However, many farmers, and especially those in developing countries and this study area, find themselves at a disadvantage as they fail to make the best use of organic recycling opportunities using earthworms. Thus, Vermicomposting could be one of the valuable options for Sahel region farmers to restore or enhance their agricultural soil's health.

The major objective of this study is to know the reaction, primary nutrient and OC status of three Vermicomposts produced with different raw materials. Specific aims of the study include: Producing Vermicompost and comparing the production indices of different Vermicomposts

Materials and methods

This research was carried out at Federal University Gashua (FUGA). Gashua is a community located on Latitude: 12°52'26" N Longitude: 11°02'26" E Elevation above sea level: 339 m = 1112 ft in Yobe State, northeastern Nigeria.

Experimental design

The experiment was laid out on a Completely Randomized Design (CRD) where three vermicomposts are produced using three different ingredients (Fiber) in three times replica containers. The main raw materials are that make the three Vermicompost treatments are:

1. Municipal Waste (M_W)
2. Dried Typha Grass (T_P)
3. 50% Municipal Waste + 50 % Dried Typha Grass ($M_W T_0$)

Vermicompost production

Organic waste in the forms; Farmyard Manure (FYM), Municipal Refuse, and the White Grub worms were obtained from the Animal Science Teaching and Research Farm,

Faculty of Agriculture, Federal University, Gashua. Typha grass was obtained along Garbi River, a delta on the Hadejia-Nguru Wetlands, all in Yobe State, Nigeria.

During preparation for the compost production, all organic wastes were sorted and air dried for a week. 11 white grub worms were introduced to perforated pots each for the three compost ingredients mentioned in 3.3 above, upon which an equal weight of the raw materials and farm yard manures was added. 100ml of distilled water was then sprinkled on the mix and the containers were covered. The same procedure was replicated three times for each treatment. Typha grass was shredded to increase its surface area and increase decomposition during rate. This setup was monitored and turned daily for three weeks and data was taken on the 21st day after set up.

Sampling and determination of Vermicompost nutrient status

A sample was collected from each of the matured Vermicomposts and used to determine Electrical Conductivity (EC), pH, Total Nitrogen (N), Available Phosphorus (P), Exchangeable Potassium (K) and Organic Carbon (OC) using standard laboratory procedures at the soil science laboratory, Bayero University Kano.

EC and pH were determined with its respective meters using the method as described in (Mitchell and Soga, 2005). Total Nitrogen (N) was determined using the Kjeldhal digestion method in (Bouajila and Sanaa, 2011). Phosphorus (P) in Cmol/Kg was determined using Extractable Phosphate Bray and Kurtz –Method (Department of Sustainable Natural Resources, 1995), and converted to mg/Kg using the conversion factor 1cmol/Kg =10,000mg/Kg. Exchangeable Potassium (K) was determined using the Ammonium saturation method described by (Burt, 2014). Organic Carbon (OC) was determined using wet oxidation using the method of Walkley and Black (1934).

Method of data collection

Data on mortality rate, number of live worms, weight of worms and compost weight were collected and recorded from Sample containers at compost maturity.

White grub worms species Mortality rate:

The mortality rate of white grub worms which were placed in the different prepared Vermicompost medium for the experiment was recorded by turning the sample with a spatula and watching with eye visibility count at compost maturity.

Percentage of live White grub worms:

Live worms in the respective pots after compost maturity were counted and the percentage was determined from the initial number at the start of the experiment.

Weight of White grub worms:

The weights of the worms in 3.5.2 above were determined using a digital weighing balance.

Vermicompost weight:

Matured Vermicompost of all pots was weighed after the removal of live and dead worms using a weighing balance.

Data analysis

The Vermicompost production indices data recorded from all pots was subjected to Analysis of Variance (ANOVA) using STAR 2.2 edition.

L.S.D was employed for mean separation where significance existed at 0.5% probability.

Results and Discussion

Table 1 and figure 1 above show the production indices of the three vermicomposts produced in this study. Vermicompost weight shows a statistically significant variation among the composts at maturity, M_W with 301g is higher in biomass and statistically different from T_P with 204 g which was also significantly different from $M_W T_0$ which weighs 249g. The percentage of live worms is highest in M_W as a substrate at 64.5, followed by 24.7% for $M_W T_P$. The $M_W T_P$ seemed to be the most favorable substrate to the worms, as the average live worm weighed 59.1g showcasing statistical supremacy over $M_W = 40g$, and $T_P = 20.8g$. In terms of worm mortality, however, the highest value indicates a worse substrate for the worm's survival and in that, single Typha T_P proved to be the worst. At the same time, $M_W T_0$ was the best attesting to the magnitude of the worms' average weight in grams.

Table 1. Vermicompost production indices

Vermicompost type	Vermicompost weight (g)	Live worms (%)	Earthworm weight (g)	Mortality rate %
M_W	301 ^a	64.5 ^a	40.0 ^b	30.0 ^b
T_P	204 ^c	5.5 ^c	20.8 ^c	66.9 ^a
$M_W T_0$	249 ^b	24.7 ^b	59.1 ^a	28.0 ^c
Mean	251.3	31.6	39.9	48.3
LSD	15.79	5.52	4.08	18.8

M_W = Municipal Waste Vermicompost; T_P = Typha Grass Vermicompost;

$M_W T_0$ = 50% Municipal Waste + 50 % Dried Typha Grass

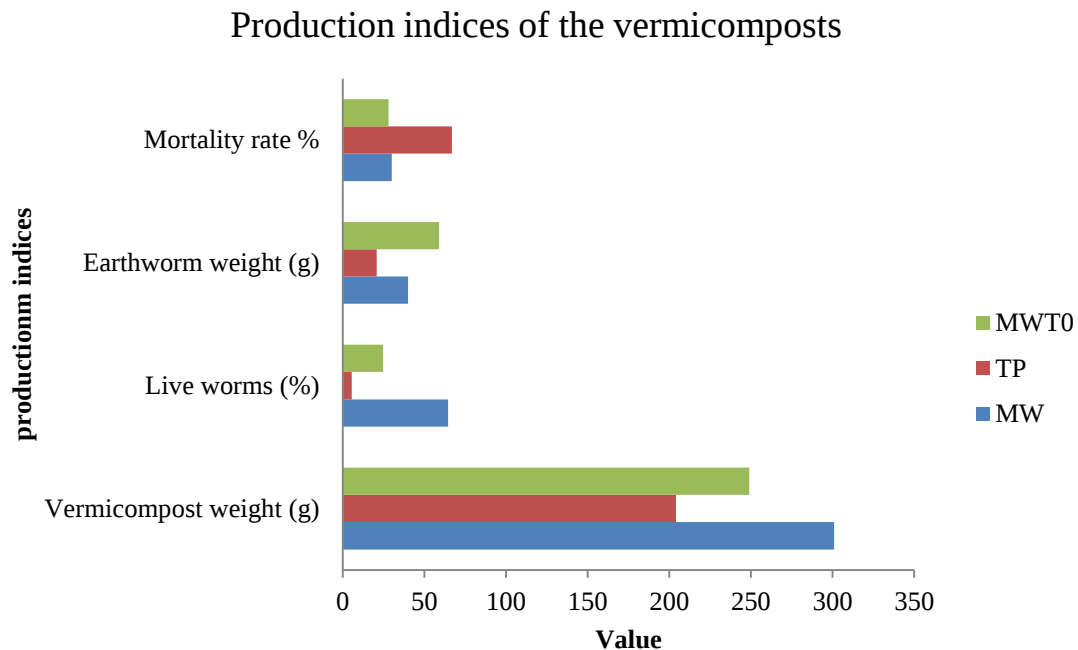


Figure 1. Vermicomposts indices during production

Looking at the production indices, the two vermicomposts that contain municipal waste (M_w) performed better in this study. This could be probably due to its constitution of many species of biodegradable wastes sourced largely from table drops and household wastes, thereby supplying a variety of substrates for the worms to thrive. (Garg and Gupta, 2009; Lim et.al., 2015) mentioned a similar possibility as a reason for production and nutrient level disparity in agro-industrial waste. Also, Type grass as a substrate may be rich in Carbon and Hydrogen but less in peptides, which may diminish its performance as against M_w containing vermicompost (Ahirwar & Hussain, 2015)

Table 2. Vermicomposts reaction, primary nutrients (NPK), and Organic Carbon status

Parameter	M_w	T_p	M_wT_0
pH in H_2O	6.85	7.26	7.37
EC (dS/m)	0.35	0.36	1.10
Total Nitrogen –N (%)	1.95	0.80	0.80
Phosphorous – P ($mgKg^{-1}$)	0.47	0.35	0.37
Potassium –K ($mgkg^{-1}$)	0.72	0.49	0.4
Organic Carbon (%)	2.80	1.20	1.80

M_w = Municipal Waste Vermicompost; T_p = Typha Grass Vermicompost

M_wT_0 = 50% Municipal Waste + 50 % Dried Typha Grass

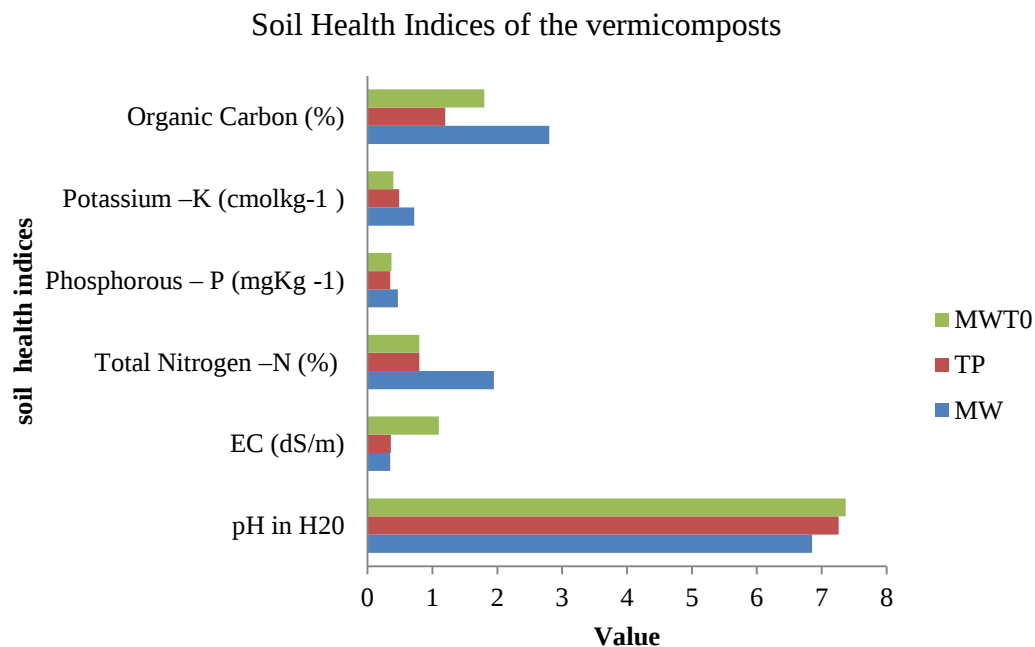


Figure 2. Soil health Indices of the produced Vermicomposts

Table 2 and figure 2 shows the reaction and primary nutrients (NPK) status of the vermicomposts produced in Table 1 above. Both T_p and M_wT_0 vermicomposts are neutral in terms of reactivity (pH), which attests to a good quality soil amendment and provides the

favorable conditions needed for plant and Rhizosphere conditions for good production. Percentage Organic Carbon (OC) in the vermicomposts produced is at least 1% higher in M_W than either of T_P and $M_W T_0$. 2.80%, 1.20%, and 1.80% was the respective percentages for M_W , T_P , and $M_W T_0$. The recorded variations in the selected soil health indices could be as a result of the nutritional constitution of the major ingredients of the vermicomposts as reported in (Barik et al., 2011). Also, the OC content of all the produced vermicomposts, is way above the average OC content of the soils of the study area reported in many literature (Alhassan et al., 2018; James & A, 2019; Sani et al., 2019; Wikipedia, 2020). This is an indicator of OC supplementing power of all Vermicompost produced (despite different levels) when and if incorporated to the soil.

Conclusion

In conclusion, the use of organic fertilizer especially Vermicompost has a great impact on improving the physical, chemical, and biological properties of the soil. Most importantly, Vermicomposting is the easiest way of conserving the soil and reducing environmental waste. Findings in this study establish the superiority of organic wastes from Municipal dump site. The product from such fibers and organic materials produced the best set of Vermicompost production indices and Vermicompost-soil health indicators.

Recommendation

Taking this research as a pilot, we recommend subsequent studies that will research the substrate type and rate, for a more informed compost recommendation and the undertaking of organic farming in the Sahel region.

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Pesticides and Soil Environment: An Age-Linked Concept

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Abstract

Pesticide was considered complex substances intended for preventing, destroying, or controlling any pest including vectors of human or animal diseases. They are specific chemicals, which contain both “active” or energetic and “inactive” or inert ingredients. The term pesticide includes herbicide, insecticide, nematicide, sanitizer, bactericide, insect repellent, animal repellent, antimicrobial, fungicide, disinfectant, molluscicide, and avicide among others. They are classified based on the mode of entry, mode of function and action, and their chemical composition. These pesticides played a key role in controlling and mitigating variety of agricultural pest and diseases in farm, garden. They contrary, affect soil functional service and great biological biodiversity including human and his environment. Many factors and processes are involved in the transfer, transport and degradation or biochemical conversation of pesticides in soil. The soil factors are the soil organic matter, soil pH, temperature, nutrients, moisture, infiltration rate, aerobic and anaerobic, soil texture and structure. The combined processes are physical, biological, and chemical with great conversion on weathering, hydrolysis, oxidation-reduction, photolysis humification, cheluviation, organic sorting, translocation, *eluviations*, *illuviation*, calcification, podsolisation, gleying, and leaching. Seven important subjects have been treated in a synopsis manner – major groups of pesticides, pesticide toxicity (acute and chronic effects), processes affecting pesticides in soil, pesticides and its ecological effects (soil, crop, biota and human), step by step procedure and soil sampling, techniques involving analysis of pesticides residues in soil, and bioremediation and biodegradation approaches.

Keywords: pesticides: groups, processes, effects, techniques and bioremediation

Introduction

Sustainable agriculture means ensuring food security and better livelihood in rural and urban areas, and this depends on the broad diversity of unnaturally produced chemicals, including pesticides, inorganic fertilizers, and bio-chemicals (Cooper and Dobson, 2007; FAO-WHO, 2014; European Union, 2021). The word pesticide comes from two terms namely ‘pest’ and ‘cide’. Pest is a name used to define any plant or animal or soil organism which is

detrimental or harmful to soil productivity, agronomic plant growth, pastures, forest shrubs and fishes (Usman, 2020). On the other hand, the term ‘cide’ is a Latin word that means ‘to kill’ or ‘to destroy’ (Usman, 2020). Hence, the term ‘pesticide’ can be considered as a complex name that includes all chemicals used to kill or control pests either in agricultural field or in other environments such as store rooms, human houses and gardens. According to FAO (2002) pesticide can be defined as any substance or mixture of substances intended for preventing, destroying, or controlling any pest including vectors of human or animal diseases, unwanted species of plants or animals causing harm during, or otherwise interfering with, the production, processing, storage, or marketing of food, agricultural commodities, wood and wood products, or animal feedstuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. It may also be regarded as a chemical or biological agent that deters, incapacitates, kills, or otherwise discourages pests in agriculture; and the target pests may include insects, plants pathogens, weeds, mollusks, birds, mammals, fish, nematodes (round worms) and microbes that destroy property, cause nuisance or spread diseases, or disease vectors (FAO, 2002). Kortekamp (2011) also viewed pesticides as any substance or mixture of substances intended for controlling pest and diseases in crop production.

Twenty-seven years ago (1995 to date), the global pesticide consumption is believed to have reached 2.6 million metric tons of active or energetic ingredients; however, this consumption of pesticide has now (2023) reached 3.53 million metric tons (BRC, 2023). The global commercial market of the active pesticide chemicals, also reached \$90.5 billion in 2022 and attained an increased 8.8% (\$98.42 billion) in 2023 (BRC, 2023). Majority of these pesticide chemicals, are marketed illegally. According to the Transnational Alliance to Combat Illicit Trade in agrichemicals and pesticides (TRACIT, 2019), illegal pesticides commercially marketing globally, can be considered as outdated and unauthorized pesticides, pesticides without appropriate regulations, pesticides without tests and licenses, fake pesticide products, un-labelled and fake-labelled pesticide products, and refilled pesticide containers and packages found anywhere in the world.

The major criminal enterprise regarding illicit pesticides marketing in Africa is serious and alarming (Medina-Pastor and Triacchini, 2020; United Nations, 2020). Typically, a global operation called Silver Axe was reported to have seized 1346 tons of illicit pesticides, which were estimated to worth up to €94 million (equal to NGN56400000000), during just the first four months of 2020 (Europol, 2020).

Existing knowledge indicates that the agricultural use of pesticide chemicals contributes greatly to global ecosystem contamination (FAO-WHO, 2018, 2019; Sharma et al., 2019; Bonvoisin et al., 2020; Brescia, 2020; Lin et al., 2022; Geissen et al., 2022). With an increased pesticide use, questions are rising on potential effects regarding public health, soil and water contamination and environmental ecosystem (United Nations, 2018; FAO-WHO, 2020; Braga et al., 2020). This has led to an extensive review of the global pesticide legislation and the scale of challenge in reaching the global harmonization of food safety standards, which highlighted the presence and future consequences of pesticides to global ecosystem and human resources (Möhring et al., 2020). Thus, selection of pesticides to reduce human and environmental health risks was highly recommended in agriculture (Jepson et al., 2020). And, pesticide management approach towards protecting the safety and health of

farmers is binding (Mohammad et al., 2018). Similarly, assessing the farmers' safety and protective behaviour to use pesticides in the farms, was also looked to be necessary (Moradhaseli et al., 2017).

The risk assessment of pesticide molecules is surface soil, water components and plant biomass including animal feeding on the plant biomass has been also demanded in many calls (Ngolo et al., 2019). Mapping the impact of pesticides trading is equally important (Tsimbiri et al., 2015; FAO-WHO, 2014; European Union, 2017; United Nations, 2020). This paper focused on background concept of pesticides in soil, and addressed the following subject areas: major groups of pesticides, processes and factors affecting pesticides in soil and microbial degradation, effects on soil organisms, crop damage and human health, techniques involving analysis of pesticides residues in soil, and bioremediation approaches. This overview, demonstrated and addressed the key issues regarding pesticide and its diverse health issues to soil, plant, human and environment. It is believed that the information has relevance to National Agency for Food and Drug Administration and Control (NAFDAC), and National Environmental Standard and Regulations Enforcement Agency (NESREA), all based in Nigeria. Likewise, it would undoubtedly serve as relevance materials to both academic and public health centers, globally.

Major groups of pesticides

Pesticides are specific chemicals, which contain both “active” or energetic and “inactive” or inert ingredients. The former is referred to ingredients, which are sparkling and capable of preventing, destroying, repelling or mitigating a pest of plant and human vectors, present in all pesticide products (US-EPA, 2017). They are considered as plant regulators, defoliants, desiccants, or nitrogen stabilizers, and behave very active in soil causing severe consequences to biological organisms (Usman, 2020). These active ingredients are classified as conventional (pure chemicals), antimicrobial (mixtures of substances), and biopesticides (biological pesticide) (US-EPA, 2017). On the other hand, the inactive ingredients are stationary and immobile in soil, useful for product performance and usability, and contain at least one active ingredient and other calculatedly added inactive ingredients (US-EPA, 2017).

According to Drum (1980), pesticides can be grouped based on three classes, namely, function and action, mode of entry and chemical composition. Fishel and Ferrell (2013) noted that pesticides can be classified based on their function on target pest into the following classes, as outlined by Usman (2020).

Table 1. *Pesticides class, description and examples (after Usman, 2020)*

No.	Pesticide class	Description	Example
1	Insecticides	These are pesticides formulated to kill, damage or alleviate one or more species of insect found to be a problem to crops. Functions include the disruption of the pest nervous system, and damaging their exoskeletons. Kill insects and arthropods.	Aldicarb
2	Fungicides	This class of pesticides produced mainly to kill fungi and other related organisms such as blights, mildews, molds and rusts.	Azoxystrobin
3	Bactericides	These are produced specifically to kill bacteria and acts against any bacteria that are parasite to plant or biological organisms useful to soil productivity.	Copper complexes
4	Herbicides	These groups of pesticides are produced to destroy weeds and other unwanted plants in farms and gardens.	Atrazine
5	Acaricides	These are pesticides that kill mites and other related organisms feeding on plants and animals.	Bifenazate
6	Rodenticides	This group of pesticides is produced to control rodents, mice and other related organisms.	Warfarin
7	Algaecides	These are used to control or kill growth of algae.	Copper sulfate
8	Larvicides	These are used to inhibits the growth of larvae.	Methoprene
9	Desiccants	These act as reagent on plants by drying their tissues.	Boric acid
10	Repellents	This class of pesticides is used to repel pests by its taste or smell in farm and garden.	Methiocarb
11	Ovicides	This class of pesticides is designed to hinders the growth of eggs of insects and mites.	Benzoxazin
12	Virucides	These pesticides are used to control viruses in soil and plant.	Scytovirin
13	Molluscicides	This class of pesticides is used to inhibit or kill mollusc 's i.e. a snail that usually disturbing growth of plants or crops in farm and garden.	Metaldehyde
14	Nematicides	These are mainly formulated to kill soil nematodes that act as parasites of plants in farms and garden.	Aldicarb
15	Avicides	These pesticides are used to kill birds, which attack rice, pearl millet, wheat and sorghum.	Avitrol
16	Lampricides	These are used to target larvae of lampreys, which are jawless fish-like vertebrates in the rivers and oceans.	Trifluoromethyl nitrophenol
17	Piscicides	These pesticides are formulated to act against parasite fishes.	Rotenone
18	Silvicides	These are used to acts against woody vegetation.	Tebuthiuron
19	Termiticides	These are used to kills termites.	Fipronil

According to Yadav and Devi (2017), classification of pesticides based on mode of entry, can be understood as systemic (non-contact absorbed by plant), non-systemic (contact), stomach poisoning and stomach toxicants, fumigants and repellents. The non-contact is absorbed by the plant and soil, the contact enters the body of pests through their epidermis and causes death, the stomach poisoning enters via mouth and causes death, the fumigants enter the body of pests through their tracheal or respiratory system and caused death, and the

repellents served as disturbance agent to pest, and are capable of deterring the pests from the farm (Usman, 2020).

By and large, classification based on chemical composition of a given pesticide is generally the most important way of understanding pesticide behavior in soil and plant (Handford et al., 2015; Usman et al., 2017). Normally, this classification, gives the knowledge about the physical and chemical properties of pesticides, as well as the active ingredients included (Yadav and Devi, 2017). It also, provides the efficacy and extent of pesticides toxicity and the information that is useful in determining the mode of pesticide application, safety measures, and immediate clarification in case of any accident (Usman, 2020). Four groups of pesticides, were reported namely, organochlorine, organophosphates, carbamates, and synthetic pyrethroids pesticides. Thanks to the works of Yadav and Devi (2017) and Usman (2020) who have provided a comprehensive overview of these three groups of pesticides as presented below.

1. Organochlorine pesticides: These pesticides are used in 1940s and 1960s for the control of mosquito and agricultural pests. They are chlorinated hydrocarbons, which refers to organic compounds attached with five or more chlorine atoms (chlorinated aromatic molecules). Examples are DDT, methoxychlor, dieldrin, chlordane, lindane, endosulfan, benzene hexachloride, kepone, mirex, toxaphene and aldrin. These chemicals worked effectively by disrupting the entire nervous system of the insects leading to convulsions, paralysis and death.

2. Organophosphates pesticides: These pesticides are widely used in farms and garden, homes and offices, grazing lands and sport areas. They are the derivatives of phosphoric acid characterised as biodegradable compounds with less soil contamination effects. They worked as stomach, contact and fumigant poisons leading to nerve damage, paralyse and death of an insect. Examples are diazinon, chlorpyrifos, carbophenothion, endosulfan, parathion, glyphosate and malathion. These pesticides are highly toxic to insects but are relatively minus to human and domestic animals such as cows, goats, sheep and camels.

3. Carbamates pesticides: These pesticides are derived from carbamic acid primarily to kill insects. The mode of action is shorter compare to that of organophosphate but interfere in the same way in the nervous system of insects and as stomach, contact and fumigant poisons. Examples are carbaryl, carbofuran, propoxur and aminocarb.

4. Synthetic pyrethroids pesticides: These are pesticides with special active ingredients, which can be synthesized by duplicating the structure of natural pyrethrins 'pyrethrum-like'. They are similar to natural pyrethrins that are produced by the flowers of pyrethrums (*Chrysanthemum cinerariaefolium* and *C. coccineum*), but with longer residual effects than natural pyrethrins. They are highly toxic to insects and fish but slightly toxic to mammals and birds, widely considered to be amongst the safest insecticides for use in foods and on grains. Examples are Cypermethrin and Permethrin.

Pesticide toxicity: acute and chronic effects

Toxicity of pesticide, length and magnitude of exposure, has been considered as the key determinants of the degree of harmful impact on soil organisms and human health (Lorenz, 2009). This can be understood in two forms namely acute and chronic toxicity. According to Yadav and Devi (2017) acute toxicity is the ability of a chemical pesticide to

cause harmful effects in human or biological organism within a very short period after inhalation or contact, whereas chronic toxicity is the ability of a chemical pesticide to cause adverse health effects which follows from long-term exposure to a chemical; and this is expressed in terms of lethal dose 50% (LD₅₀) or lethal concentration 50% (LC₅₀). This LD₅₀ is regarded as the single exposure dose of the poison per unit weight of the organism required to kill 50% of the test population, where the population is genetically homogeneous expressed in milligram per kilogram (mg/kg) body weight (Usman, 2020). According to Singh and Mandal (2013) acute effects occurs as a results of accident and misused, which follows due to untaught concept. Pesticide Action Network (PAN, 2012) reported that the major symptoms that occurs from the chronic effect include birth defects, fetus deformity, genetic changes, blood and nerve disorders, endocrine disruption, and reproduction abnormalities. Continuous exposure to chemical pesticide particularly during application without protective clothes may cause chronic illness. This has been the fact that the joint FAO/WHO Meeting on Pesticide Residues (JMPR) and the Joint FAO/WHO Meeting on Pesticide Specifications (JMPS) has led to the compilation of broad lists of pesticides which can serve as a guide to the concept of pesticides in the field of agriculture and environment in general. The information may be useful to both academic environment, National Agency for Food and Drug Administration and Control (NAFDAC), and National Environmental Standards and Regulations Enforcement Agency (NESREA) operating in Nigeria. `

Processes and factors affecting the transfer and transport of pesticides in soil

The processes that involved in the pesticides communication with soil and biochemical conversion, are complex and dynamics. Usman et al. (2017) considered these as sorption, adsorption, physical and chemical processes, and microbial degradation. According to Usman (2020) as noted from the detailed study of soil formation and soil profile development (Jenney, 2009), numerous processes are involved in the transfer and transport of pesticide molecules in soil and plant. These include the physical, chemical, biological and ecological processes, which are set of mechanisms, considered complex in soil formation (Usman, 2013). It is evident that when pesticide get contact to soil, the following processes play a key role in the potential degradation of pesticides (Ngolo et al., 2019). These soil processes can be understood from the following viewpoints (Waugh, 2000; Usman, 2020):

1. Weathering: This is a breakdown of soil particles by physical, chemical and biological factors. During this process, pesticide molecules can be further broken, and affect the soil materials.

2. Humification: This is a process of decomposition of organic matter into humus. Pesticide molecules attached to the organic materials, can be included into this decomposition and affect the soil particles.

3. Cheluviation: This is the transport of chelates or nutrients and organic acid downwards through the soil profile. Molecules of pesticides are said to be transported into the various parts of soil profile during this process.

4. Organic sorting: This is the reorganization of minerals and organic matter into the horizons. The arrangement may contribute to the great distribution of pesticide molecules in soil voids.

5. Translocation of soil materials: This is the movement of soil components in a form of solution, suspension, biological activities or direction (downward and upward).

Translocation is one of the most serious soil process that moves pesticide molecules easily from one area to another by means of solution, suspension and/ biological agent.

6. Eluviations: This is a process of washing out of materials – the removal of organic and mineral matter from the A-horizon. Pesticide molecules that decompose with organic material during humification, can be washed out to A-horizon.

7. Illuviation: This is a process of in-washing – the re-deposition of organic and mineral matter in B-horizon. Similarly, pesticide molecules that are decomposed along with organic material during humification, can be washed-into B-horizon.

8. Calcification: This is a process of calcium accumulation in B-horizon – occurs where precipitation is equal or slightly high than evapotranspiration (tropical areas). During this accumulation of calcium, molecules of pesticide can be carried away by rainfall to other part of the surface soil.

9. Podsolization: This is the removal of iron and aluminium oxides together with humus – occurs where precipitation is greatly more than evapotranspiration (cool or humid areas). During this removal process, molecules of pesticide can be removed by the rainfall to other parts of the surface soil.

10. Gleying: This occurs when the output of water from the soil system is restricted, giving anaerobic or waterlogged soil conditions. Particles of pesticide can be deposited along with gley materials.

11. Leaching: This is a removal of soluble material in soil solution – occurs where precipitation exceeds evapotranspiration while soil drainage is good. Pesticide molecules can be leached into the soil profile zones, and contaminate the soil.

Soil organic matter, soil pH, temperature, nutrients, moisture, infiltration rate, aerobic and anaerobic, soil texture, and structure, are considered the most common factors affecting and controlling the effectiveness of soil-applied pesticides as well as the bio-chemical degradation in soil (Katagi, 2004). For example, Gold et al. (1996) noted that in the bio-chemical conversion of pesticides, soil pH and clay content are found to affect the persistence of *bifenthrin*, *chlorpyrifos*, *cypermethrine*, *fenvalerate*, *permethrin*, and *isofenphos*. This conversion was noted to be faster in the silt loam soils compared to sandy-loam and sandy soil for soil affected by *imidacloprid* and *diazinon* (Jones and Ananyeva, 2001). The persistence and biodegradation of these two pesticides in soil together with *pencycuron* degraded faster in coastal saline soil than in alluvial soil and soil amended with decomposed cow manure (Hafez and Thiemann, 2003). Racke et al. (1994) noted that herbicides such as atrazine and trifluraline disappeared more rapidly under anaerobic conditions than under aerobic conditions. However, this might be very limited due to the absorption process that prevents the release of pesticides into the soil solution and the loss by causing dislocation during leaching and runoff (Pal et al., 2005).

Pesticide degradation in soil

The term ‘degradation’ as applied to the concept of pesticides in soil means breakdown of pesticide molecules in soil solution. Katagi (2004) considered this breakdown as a process of pesticides dissolving in soils, which results in the conversion of its molecules into simpler compounds such as H_2O , CO_2 , and NH_3 . Buchel (1983) noted that this breakdown might further be increased as a result of chemical reactions such as solubility, volatilization, adsorption and desorption, hydrolysis, photolysis, microbiological catabolism, and

metabolism; considered the major route of mineralization (Usman, 2020). These sets of processes are controlled by three modes of degradation in soil namely: biological (breakdown by micro-organisms), chemical (breakdown by chemical reactions, such as hydrolysis and redox reactions), and photochemical (breakdown by ultraviolet or visible light). Microbes in soil used pesticides as a food source under biotic and abiotic transformation processes (Gavrilescu, 2005). Usman (2020) noted that the biotic conversion is mediated by microorganisms, while abiotic conversion embroils the processes such as chemical and photochemical reactions. The key factors involved in these two conversions mostly in soil-water conditions, are hydrolysis, oxidation-reduction and photolysis (Burns, 1975). However, hydrolysis and redox-reactions are the main regulators in sediment conditions, with redox reactions mediating in aquatic environments by direct or indirect photolysis (Burns, 1975). Similarly, hydrolysis and redox reactions are considered the major processes controlling the breakdown of pesticides in soil liquid and solid forms (Usman et al., 2017). Soil moisture, temperature, aeration, pH, and organic matter are considered the key components of microbial degradation in soil (Drum, 1980).

According to Usman (2020), surface and sub-surface soil medium are the positions where chemical degradation of pesticides occurs although very high at the surface medium. It has been described that soil temperature, moisture, pH, aeration, light and the ability of pesticide molecules to adhere and adsorb to soil particles, are the major factors enhancing the chemical degradation of pesticides in soil (Drum, 1980; Usman, 2020). Photochemical degradation, on the other hand, is an abiotic process that describes the dissipation of pesticides where molecular excitation by absorption of light energy results in various organic reactions (Katagi, 2004). This form of pesticides degradation in soil is influenced by the intensity and spectrum of sunlight, length of exposure, and the properties of the pesticide molecules (Katagi, 2004).

Pesticides and its ecological effects: soil, crop, biota and human concerned

Pesticides as chemical agent is used for preventing and destroying pest to achieve high crop yield and sustainable food security (Handford et al., 2015). However, these chemicals have more negative impact the key components of the ecosystem: soils, crops, water, forest, biota, and human (Zikankuba et al., 2019; Ndungu et al., 2019; Bonvoisin et al., 2020; Brescia, 2020). The national and international concern about their various effects remains an area of interest (Yao, 2020). Soils, crops, water and the human environment are four components, that must be put into consideration with regard to pesticides and ecological effects. According to Joko et al. (2020) illicit pesticides, are highly toxic and might poison almost all components of human and biological lives including water bodies, soil voids, aquatic organisms and the overall ecosystem. Usman (2018) emphasized that soil quality, plant health, water quality and human health, must be protected from the chronic effects of pesticides. These four subject areas have been regarded as the major target of pesticides when released into the environment for a particular purpose (Lai, 2017; United Nations, 2018; FAO-WHO, 2019). The pesticides molecules released during spraying in the field, immediately come into contact with soil and plant residues (Bollag et al., 1992; Braga, 2020; Lin et al., 2022; Geissen et al., 2022). The soil and its biological components (parent

materials, biota and biodiversity, water), the plant and biomass, and also, the atmosphere and air circulating, are at high risk of becoming contaminated by the synthetic molecules of pesticides (Yao, 2020).

Soil biota play a vital role in soil quality and soil fertility development, and plant growth as well (Usman et al., 2016). The interaction between these biological organisms and pesticides has effects on their biodiversity, and soil-crop health relationship (Usman et al., 2017). Sebiomo et al. (2011) noted pesticides decrease the microbial population and cause significant damage to soil and plants. Pesticides such as butachlor were reported to suppress the microbial population and deter their enzyme activities in soil (Min, et al., 2007; Xia et al., 2012). Other pesticides were observed to have severe effects on crops, and are capable of destroying great number of non-target organisms (Constenla et al., 1990). These severe effects reduce the functional services in soil system, eliminate the biological diversity, and damage plant systems at a very early stage of growth (Sharma et al., 2019). According to Kalia and Gupta (2004), pesticides disrupt the food web and put the entire ecological system at very risk of altering the biosynthetic mechanism, affecting the protein synthesis and cellular membrane, and disorderly plant growth. Study by Mayeetreyee et al. (2013) noted a significant reduction of heterotrophic aerobic bacterial count and fungal population in soil treated with paraquat and glyphosate pesticides. Similarly, a group of herbicides such as butachlor, pyrazosulfuron, paraquat and glyphosate have been observed to cause damage to plant biomass and delay a substantial microbial function on the proper decomposition of organic matter (Bolter et al., 2006). Other studies of recent analyses in this regards include the recovery of selected drugs and herbicides from soil (De Carlo et al., 2015), the analysis of five neonicotinoid insecticides and their primary metabolite in cucumbers and soil (Abdel-Ghany et al., 2017), determination of dioctyl diethylenetriamine acetate residues in soil (Gong et al., 2018), determination of polyoxin b in cucumber and soil (Song et al., 2019), monitoring of 218 pesticide residues in clay loam soil (Acosta-Dacal et al., 2021), Simultaneous multi-residue pesticide analysis in southern Brazilian soil based (Do Amaral et al., 2022), and multi-residue method for trace analysis of pesticides in soils (Rösch et al., 2023).

The synthetic pesticides molecules, play a major role in contaminating environmental ecosystems, and affect many aspects of human health developments as well (Haggblade et al., 2019). They are poisons and can be hazardous when misused in the farm or garden (FAO-WHO, 2019; United Nations, 2020). They poisoned almost all components of the human body including hairs, skin, eyes, sliver, and clothes (Lai, 2017; Joko et al., 2020). Many studies reported different pesticide cases on human and environmental health impact (Khan, 2009; Handford et al., 2015; van Wendel de Joode et al., 2016; Larsen et al., 2017; El-Haoud et al., 2017; Mohammad et al., 2018; Mora et al., 2018; Cappa et al., 2022; Marks-Perreau et al., 2023). The complex environmental and human health effects of pesticides reported by these studies are largely due to the commercialization of the illicit chemicals (European Union, 2021). The toxicity level and formulation of the energetic ingredients contained in these outdated pesticides are produced without test and quantification (United Nations, 2018; TRACIT, 2019). This toxicity of pesticide molecules has detrimental effects on human health (Lorenz, 2009). Diseases such as brains (neuroblastoma) cancers, soft tissue sarcomas, colorectal and testes carcinomas; hormonal imbalances leading to infertility, breast pain, menstrual disturbances, adrenal gland exhaustions and early menopause among others, have

been linked to high level of exposure to toxic pesticides (Larsen et al., 2017; van Wendel de Joode et al., 2020). The common symptoms reported include eyes and skin irritation, body shivering, headaches, body aches, skin rashes, poor concentration, nausea, dizziness, impaired vision, cramps, panic attacks and in severe cases coma and death could probably occur (Mohammad et al., 2018; Joko et al., 2020). The human birth effect, infants and children multiple diseases cases are also noted as a result of pesticide use in agriculture (Larsen et al., 2017; Mora et al., 2018; Widyawati et al., 2020). This has also linked to problems related to inability to speak fluently, hormonal imbalances leading to infertility, breast pain, menstrual disturbances, adrenal gland exhaustions, early menopause, immune system dysfunction leading to immune suppression that cause potentially serious health risks and also subject to malnutrition (Xavier et al., 2004; Tsimbiri et al., 2015). These complex health issues are considerable (WHO, 2017; Zikankuba et al., 2019), and need to be on a regular check and balance assessment particularly in northern Nigeria where many rural farmers are mingling with pesticides on daily times (Usman, 2020).

Techniques involving analysis of pesticides residues in soil

The human relationship with soil is a long-term friendship and has recorded many benefits and detriments as well. The entire soil body represents one of the most complex mediums with diverse functional services and interactions of pesticides that take place through various processes and compound factors (Bollag et al., 1992; Usman and Kundiri, 2016). The use of pesticides in soil has infiltrated the existence of many residues, which are unfriendly to the soil itself, and biological organisms living within (Pelosi et al., 2021; Geissen et al., 2021). The employment of soil-based techniques for the analysis of these pesticide residues in soil has become necessary (Leo et al., 2016; Usman, 2020). This is to provide open access to short- and long-term worldly risk assessment of eco-toxicological effects of pesticides in soil bodies and biological lives including humans and the environmental ecosystem. In this development, many techniques and ideas have been used to achieve this risk assessment. The use of traditional techniques, which employed the application of examples of liquid–liquid extraction, Soxhlet extraction, sonication assisted extraction among others, are laborious, expensive, time-consuming, and require large amounts of organic solvents, which also involve many steps, leading to loss of some analyte quantity, consequences with the use of hydrocarbon solvents such as depletion of the ozone layer, and producing of carcinogenic waste (Mondal, 2020).

However, considering the historical catastrophes of pesticides in creating soil contamination and soil pollution (Usman et al., 2017; Usman, 2018), the scientific advancements, has provided some alternative techniques that are quick, easy, cheap, effective, sharp, and safe to replace previous, less efficient extraction methods for pesticide analysis (Varela-Martínez et al., 2020). These alternative techniques, include the use of solid phase extraction (SPE), solid phase micro-extraction (SPME), supercritical fluid extraction (SFE), microwave assisted extraction (MAE), microwave-assisted micellar extraction (MAME), accelerated solvent extraction (ASE), matrix solid phase dispersion (MSPD) extraction, and QuEChERS (quick, easy, cheap, effective, rugged and safe) method (González-Curbelo et al., 2022). These methods have been developed for a purpose of overcoming the shortcomings of the traditional techniques, even though some of them (e.g. SFE, ASE and MAE) are

instrumental techniques, useful for the desired purpose such as purification (SPE) and concentration (SPME) of obtained extracts (Mondal, 2020).

Step by step procedure and soil sampling

The general step by step procedures for the removal of pesticide residues from the soil is believed to begin with an advanced design of the experiment or choosing the best and friendly techniques. This will be followed by sampling, extraction, clean-up and estimation. In this regard, soil samples should be taken using pedon idea as introduced by Soil Survey Staff (2022) or from growing farm using the idea of grid pattern that should consistently distributed all over the intended farm (Mondal, 2020). For practical interest, Mondal (2020) is suggesting 3×3 grid with nine total sample proportions for smaller fields, 4×4 with sixteen sample proportions for the medium-sized fields, and 5×5 with more than sixteen proportions for larger grids and very large fields. According to him each sample site stands as a reference of one portion of the total sample. This means that soil sample has to be taken at each site with two soil plugs of about 15 cm deep and 3 to 5 cm μ ; whereas the combined two plugs at each site will become a one sample portion (Mondal, 2020).

Examples of some modern techniques of pesticide residues analysis

1. QuEChERS technique: This technique means quick, easy, cheap, effective, rugged, and safe (QuEChERS) approach, and was first introduced in 2008 by Lesueur *et al.*, (2008) after publishing their work titled ‘*Comparison of four extraction methods for the analysis of 24 pesticides in soil samples with gas chromatography-mass spectrometry and liquid chromatography-ion trap-mass spectrometry*’. Since its known procedure and techniques, the QuEChERS has received the attentions of many studies year after year (Lesueur *et al.*, 2008; Pinto *et al.*, 2009; Rashid *et al.*, 2010; Caldas *et al.*, 2011; Temir *et al.*, 2012; Rouvire *et al.*, 2012; Fernandes *et al.*, 2013; Chai *et al.*, 2014; De Carlo *et al.*, 2015; Zhou *et al.*, 2016; Abdel-Ghany *et al.*, 2017; Gong *et al.*, 2018; Song *et al.*, 2019; Chen *et al.*, 2020; Acosta-Dacal *et al.*, 2021; Do Amaral *et al.*, 2022; Rösch *et al.*, 2023). Significant achievement has been made in the analyses of organochlorine, organophosphorus pesticides, pyrethroid pesticides, neonicotinoids], carbamates, triazole, and urea derivatives, with the advanced QuEChERS (Chai *et al.*, 2014; Abdel-Ghany *et al.*, 2017; Ma *et al.*, 2020; Mohamed *et al.*, 2021; Rösch *et al.*, 2023). Many advanced and modified procedures were developed using QuEChERS more especially when analysing different pesticides in soil and plant (Lehotay *et al.*, 2007; Mohamed *et al.*, 2021; Rajput *et al.*, 2021).

2. Multiple Parameter Hazard Assessment Scoring System (MPHASS): Multiple Parameter Hazard Assessment Scoring System (MPHASS) is a technique that employed the ideas of Chemical Scoring System (CSS) introduced by O’Byrne and Ross (1988) as designed by US-EPA office of toxic substances and the Oak Ridge National Laboratory. This technique combines multiple parameters such as human, soil, water, plant and animal components of environmental ecosystem. The soil parameters include the water in soil, soil materials in *illuviation* zone, soil materials in *eluviation* zone, soil materials in rhizosphere zone; soil biota: bacteria, fungi, ant, termites and nematodes.

3. A handheld SRS microscope: A handheld SRS microscope is a direct method, and can be used for pesticide analysis in both soil and plant (Figure 1). The technique is a modern method, and can detect the pesticide residue *in situ*, with high speed, under ambient light, and

without special sample preparations, providing a convenient examination platform with a label-free detection of the pesticide residue (Lin et al., 2022).

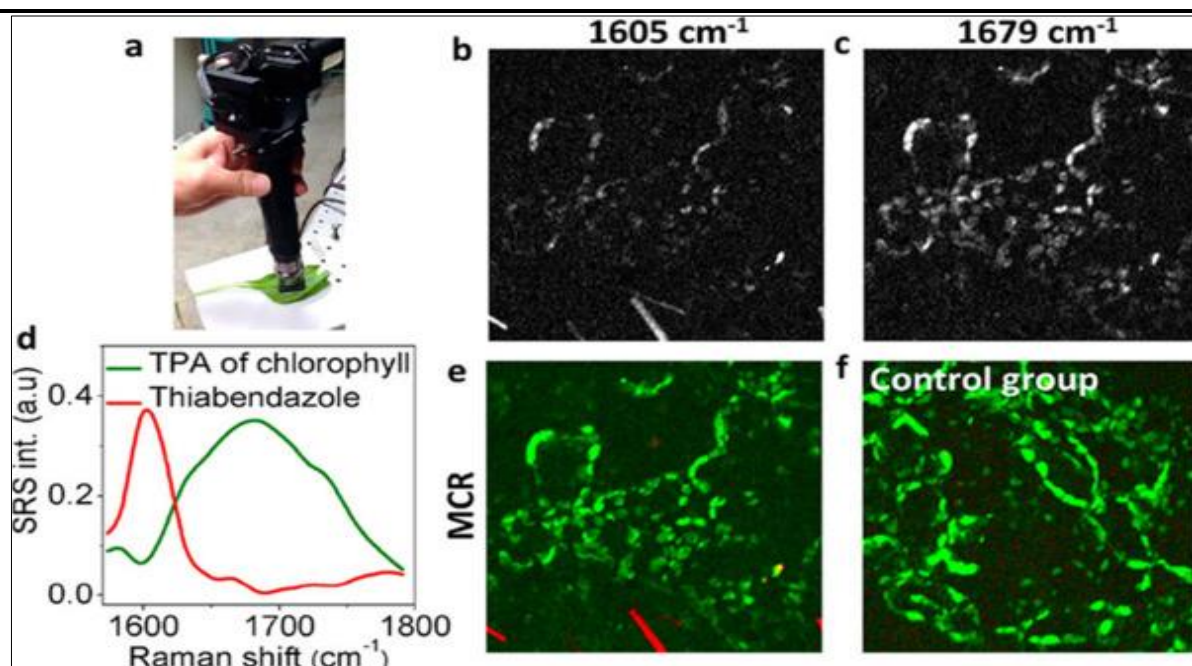


Figure 1. Typical handheld SPS microscope in situ detection of pesticide on crop*

* - This image is cited from Lin et al. (2022), and was appeared as: Fig. 37.5. In situ detection of pesticide residues on crop product by a handheld SRS microscope. (A) Digital picture of the experimental setup. (B) SRS image at 1605 cm⁻¹ of a spinach leaf. (C) SRS image at 1679 cm⁻¹ of a spinach leaf. (D) MCR output spectra. (E, F) SRS concentration maps of chlorophyll and thiabendazole. The image was Reprinted with permission from C.-S. Liao, et al., In vivo and in situ spectroscopic imaging by a handheld stimulated Raman scattering microscope, ACS Photonics 5 (3) (2018) 947–954. Copyright 2021 American Chemical Society).

4. Multi-residue method via QuEChERS techniques: This technique employed the idea of QuEChERS in a multi-purpose manner for the analysis of pesticide residues in soil. Rösch et al. (2023) have accurately quantify 146 currently used pesticides in agricultural soils with varying soil properties using a multi-residue method for trace analysis of pesticides in soils with special emphasis on rigorous quality control. According to Rösch et al. (2023) pesticides were extracted using an QuEChERS technique while chemical analysis was carried out by liquid chromatography attached to tandem mass spectrometry (triple quadrupole). Similarly, quantification was done based on matrix-matched internal standards calibration, using 95 isotopically labeled analyte analogues; the validated was conducted by an in-house prepared partly aged soil, which contains all target pesticides and by agricultural field soils with native pesticide residues (Rösch et al., 2023). They considered their multi-residue technique as highly sensitive, precise and true for regular monitoring of soils contaminated with pesticide residues.

5. Solid Phase Micro-Extraction (SPME) technique: This is one of the newly developed technique widely used for the pesticide residues analysis in soil. The technique is set to run concurrently for purification and concentration of the sample extract. According to Mondal (2020), the SPME syringe is used as the main part of this method that is visually resembling on the chromatographic system contained a 1 cm long fiber which is located within the needle of the syringe. This syringe needle is made of an appropriate polymer

deposited on the holder of fused silica. However, Mondal (2020) noted that the micro-extraction process is fixed based on the rearrangement of extract between micro-extraction fiber and sample matrix which he described as thermal in the case of the gas chromatography or by solvent elution in the case of liquid chromatography.

Conclusions

This evaluation discussed the concept of pesticide in soil with reference to the general concept of pesticide and its major groups, pesticide toxicity (acute and chronic effects), processes affecting pesticides in soil, pesticides and its ecological effects (soil, crop, biota and human), step by step procedure and soil sampling, techniques involving analysis of pesticides residues in soil. An intended study reflecting on pesticides analysis in soil, will be enlighten with the information discussed in this paper. As other similar reviews have confirmed, the content of this paper, is an appraisal towards better understanding of pesticides and how it affects the health condition of soil, plant, and human ecosystem. Analysis of pesticide in soil with modern techniques, is a good step towards better sustainable management of best use of pesticide in farms and garden. This is also vital towards better understanding of the complex effects of pesticides in soil and human environment. Some examples of the ways to be used for sustainable analysis of pesticide residues in soil are provided. These examples can be served as a guide towards better understanding of pesticide residue analysis in soil and plant.

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Author contributions

Suleiman Usman provided general text and organized the detail explanation. James O. Jayeoba improved the text quality and provide updates to it. Sani Mathew Amana improved the introductory concept and aspect of pesticide and its ecological effects. All authors contributed to the general concept of the paper.

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Modelling of Field Capacity from Basic Soil Properties on a Typical Alfisol

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Abstract

The understanding of soil water retention characteristics, including field capacity, plays a pivotal role in various agricultural studies and practices. This knowledge informs the development of irrigation and drainage schedules, assessments of soil water storage capacity (commonly referred to as plant available water), analyses of solute movement, evaluations of plant growth, and assessments of water stress levels. This study the aim of creating a regression model or equation to predict field capacity of soils in a typical Alfisol, which originated from parent material of basement complex, at the University of Ilorin Teaching and Research Farm. A total of forty-five (45) disturbed and forty-five (45) undisturbed soils samples were collected along a toposequence (upper, middle and bottom slope) at depths: 0 – 30 cm, 30 – 60 cm and 60 – 90 cm. Soil properties of the disturbed and undisturbed samples were ascertained through standard laboratory techniques and/or calculated utilizing established protocols. The measured soil properties include sand, silt, clay, bulk density, total porosity, field capacity and organic matter. A significant negative relationship between field capacity and bulk density ($r = -0.582$, $P \leq 0.05$) was found and a significant positive relationship between field capacity and total porosity ($r = 0.581$, $P \leq 0.05$) was found. A total of four different models were developed for predicting field capacity of the soil. Model four of field capacity was identified as the best model with the highest R^2 adjusted value of 0.4494. The model explains 45% of variance in the mean square errors of field capacity with sand, bulk density, silt and organic matter contributing statistically to the model.

Keywords: field capacity, regression model, basic soil properties, *Alfisols*

Introduction

Field capacity refers to the maximal water content present in soil after two or three days since saturation, with minimal drainage occurring. This parameter is a measure of maximum amount of water soil can retain for plant use (Hillel, 1998). Historically perceived as a constant soil characteristic, field capacity plays a critical role in assessing water retention and supply properties, determining irrigation requirements, and evaluating soil quality (Lal,

2006; Shao et al., 2006). Optimal plant growth typically coincides with soil water levels maintained close to or at field capacity throughout the plant's growth cycle. Therefore, maintaining soil moisture levels near field capacity is essential for effective irrigation management. As water resources become increasingly valuable, accurately measuring field capacity becomes essential for implementing efficient soil and water management strategies (Madhumita and Verma, 2011).

In the last few years, more researchers have undertaken the creation of models that simulate soil processes. These models serve the dual purpose of enhancing comprehension of crucial soil dynamics and serving as valuable tools for assessing agricultural and environmental challenges. As a result, simulation models have become commonplace in both research and management endeavors (Minasny and McBratney, 2002).

Soil moisture characteristics such as Field capacity (FC) is a fundamental soil characteristic essential for understanding plant water availability, infiltration, drainage, and solute movement. It plays a critical role in various soil water studies. However, directly measuring FC can be expensive, time-consuming, and laborious due to the high variability of soil properties across space and time. Therefore, scholars have developed alternate methods to estimate FC using more readily obtainable soil properties. These properties often include proportions of soil particle sizes (sand, silt, and clay), bulk density, total porosity, and organic matter (OM) content. Many of these estimation methods are referred to as pedotransfer functions (PTFs) as they translate existent, easily measured data into soil hydraulic data (Bouma, 1989). While PTFs are usually developed based on experimental observations, their pertinency can be limited to the specific datasets used in their creation (Donatelli et al., 1996; Wosten et al., 1999). Additionally, different PTFs can generate significantly diverse estimations for the same soil. This variability makes it challenging for users to select the most suitable PTF for their peculiar purposes (Acutis and Donatelli, 2003). Furthermore, PTF estimations often have a moderate level of accuracy. Ideally, PTF predictions would incorporate measures of reliability to enhance user confidence (Schaap et al., 2001).

Soils of the study area have been classified as *Typic Haplustalf*. The region exhibits a mosaic vegetation pattern, alternating between forest and savanna. Gravelly Alfisols are the predominant soil type, reflecting their formation over the basement complex.

Rawls et al. (1982) presented regression equations for the valuation of the soil water content at different water potentials in soils with different particle size distribution. The general form of the linear regression equation is

$$Q_p = a + b \left(\text{sand} \frac{\text{g}}{\text{kg}} \right) + c \left(\text{silt} \frac{\text{g}}{\text{kg}} \right) + d \left(\text{clay} \frac{\text{g}}{\text{kg}} \right) + e \left(\text{organic matter} \frac{\text{g}}{\text{kg}} \right) + f \left(\text{bulk density} \frac{\text{kg}}{\text{m}^3} \right) + g \left(\text{Total porosity} \frac{\text{m}^3}{\text{m}^3} \right) \quad (1)$$

Where a, b, c, d, e, f and g are regression coefficients.

This study has as an objective to create a regression model or equation for predicting field capacity of soil on a typical Alfisols at the University of Ilorin Teaching and Research Farm.

Materials and Methods

Study Area

This study took place along a toposequence at the University of Ilorin Teaching and Research Farm, Ilorin, Nigeria. The toposequence included upper, middle, and bottom slope positions. The dominant vegetation in the location is an intermix of forest and savanna, and the underlying soils formed over basement complex (Olaniyan, 2003). Gravelly Alfisols are the prevalent soil type. While the land has been cultivated in the past, it was fallow during the sampling period. The study area is situated within the Southern Guinea Savanna zone of Nigeria at about 4° 35' East longitude and 9° 29' North latitude. The elevation is 307 meters above sea level. The climate is tropical and characterized by bimodal rainfall featuring peaks in June and September and a break from mid-July to August. Precipitations rate ranges between 1000 mm to 1240 mm per annum. Daily temperatures typically fluctuate between 20°C and 35°C (Kolo *et al.*, 2012).

Soil Sampling and Laboratory Analysis

We collected soil samples at three depths 0-30 cm, 30-60 cm, and 60-90 cm along a toposequence. Fifteen small pits were dug, with five pits located at each position on the toposequence. This resulted in a totality of 90 samples collected (45 undisturbed and 45 disturbed). At each depth, undisturbed core samples were collected using metal cylinders with a height of 8.3 cm and an interior diameter of 5.5 cm. The soil was secured with a piece of calico cloth held in place with a rubber band. The samples were then labeled for identification. Disturbed soil samples were also collected at each depth using a soil auger. These disturbed samples were placed in labeled polyethylene bags. All samples were carried to the laboratory for further analysis of their physical and chemical properties using standard methods.

Soil Samples Preparation

The disturbed samples underwent a process of air drying, crushing, and sieving through a 2 mm mesh before being utilized for analysis.

Soil Properties Analysis

Particle Size Analysis

Particle size analysis was conducted utilizing the hydrometer technique outlined by Gee and Or (2002), with the inclusion of sodium hexametaphosphate (calgon) as a dispersant.

Bulk Density

Bulk density was measured using the core method with oven drying at 105°C to constant weight (Blake & Hartge, 1986). The calculation followed the standard mass-volume relationship:

$$\rho_b = \frac{M_s}{V_t} \quad (2)$$

Where, ρ_b = bulk density ($\frac{kg}{m^3}$),

M_s = Dry soil mass (Kg), and

V_t = Total volume of soil (m^3)

Total Porosity

Total porosity was calculated as:

$$\emptyset = [1 - \frac{\rho_b}{\rho_s}] \quad (3)$$

Where, $\emptyset = \text{Total porosity } (\frac{m^3}{m^3})$

$\rho_b = \text{bulk density } (\frac{kg}{m^3})$,

$\rho_s = \text{particle density assumed to be } 2650 \text{ kg/m}^3$

Soil Organic Matter (OM)

Soil organic carbon content was determined by the Walkley-Black wet oxidation method (Nelson & Sommers, 1982). Following standard practice, the percent organic carbon was converted to estimate total soil OM by multiplying by a factor of 1.724, which reflects the assumption that OM is composed of approximately 58% carbon (Brady & Weil, 1999).

Field Capacity

The determination of field capacity was done by saturating the core samples with water for 24 hours, weighing the samples after three days, and then oven-drying them at 105°C.

$$\text{Percent water at field capacity} = \frac{\text{Weight of saturated soil after three days} - \text{oven dried weight}}{\text{oven dried weight}} \times 100\% \quad (4)$$

Statistical Tool

Correlation Analysis

In statistics, when two or more variables change together in a predictable way, they are considered correlated.

A multiple correlation was used to investigate the relationship between measured pair of values. The statistical tool is given as:

$$r = \frac{(z_{ij})(z_{ik})}{n} \quad (5)$$

$$\text{and } z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \quad (6)$$

is the standardized values of the response variable X_i .

$$s_j = \sqrt{\frac{\sum (x_{ij} - \bar{x}_j)^2}{n-1}} \quad (7)$$

is the sample variance of the response variable X_i

This correlation coefficient is generally called *Karl Pearson's* coefficient of correlation. Correlation coefficient measures the degree of association (linear relationship) between two or more random variables. Correlation coefficient may be positive or negative. A significant positive correlation coefficient implies that an increase in one variable is accompanied by an increase in the other variable. While significant negative correlation coefficient implies an inverse relationship between the two random variables in question. In

contrast, a non-significant correlation coefficient indicates zero relationship between the variables under study.

A test statistic suggested by Morrison (1976) shall be used to test for significance of this correlation coefficient. This test is given as:

$$t = r \sqrt{\frac{n-2}{1-r^2}} \quad (8)$$

where, r is the so called Karl Pearson's correlation coefficient and n is the sample size. It can be shown that when H_0 is true, $t \sim t_{\alpha/2} (n-2)$ (9)

Model Development

Field Capacity

It should be noted that in multiple regression the predictions (independent variables) are assumed to be known without any uncertainty in their given values. Our model can be found useful if some or all of the assumptions hold on the datasets depending on the purpose for which we intend to use it. Because we like to use our models for both estimation and predictions we will investigate all the assumptions and correct necessary violations in the fit of the models.

Majorly, we will use diagnostic plots from the regression models to check assumptions including normality of residuals and presence of potential outliers using "Residuals versus Fitted" charts to show if there is a trend to the residuals and Shapiro-Wilk's test of residuals normality (Shapiro and Wilk, 1965) in the R software for statistical computing and graphics (Rcore team, 2013) to confirm residuals normality. Model residuals (error terms) are assumed to be normally distributed if the residual plot shows a random scatter pattern with a consistent spread of residuals around zero for each of the six predictor variables, it suggests a good model fit (Olorede *et al.*, 2013; Olorede and Mudasiru, 2013). When the points in a quantile-quantile plot, especially those in the central region, fall closely along a diagonal line, it suggests that the data are likely normally distributed. We will use standardized residual criterion to check effects of potential outliers in the dataset on the models by removing observations with standardized residuals outside the interval -2.2 according to Barnett and Lewis, 1994; John and Prescott, 1975; and Stefansky, 1972. To assess potential outliers in our models, we will calculate the minimum and maximum residuals for each model. We will then standardize these residuals by dividing them by the corresponding model's root mean square error (RMSE). Ideally, the standardized residuals should fall within a specific range. Values outside this range (expected to be between ± 1 and ± 2) might indicate potential outliers that require further investigation.

All statistical analyses, model fitting and diagnostics shall be done using the language R version 3.0.2 (R Core Team, 2013).

For multiple linear regression models of this type, statistical hypothesis tests regarding the model's parameters can be used to assess the model's effectiveness. We will therefore describe and test hypotheses about parameters of the proposed regression model collectively as well as individually. This will allow us to know if there is significant relationship between the response variables (field capacity) and a subset of the predictors. We will screen the built models based on number of significant parameters, maximum amount of

proportion of variability about the response by these parameters and satisfaction of model assumptions using diagnostic plots as aforementioned.

Rejection of null hypothesis about the full model (model with all parameters) suggests that one or more of the predictor variables significantly impacts the model. Rejection of null hypothesis about individual regression parameter (ANOVA table) indicates that the variable cannot be deleted from the model. Coefficient of multiple determination (R^2) measures extent of decrease in the variability of field capacity gotten by using the 6 predictors in the model. High R^2 alone doesn't guarantee a good regression model. (Myers and Montgomery, 1995). Adding more predictor variables will generally inflate R^2 , even if those variables don't meaningfully contribute to explaining the data's variance. This can lead to models with high R^2 that perform poorly on unseen data. To address this issue, some researchers prefer using *adjusted* R^2 (Myers and Montgomery, 1995).

Generally, R^2_{adj} can actually decrease when adding irrelevant variables to the model. A marked difference between R^2 and R^2_{adj} is a high possibility of the inclusion of irrelevant or statistically insignificant terms. We are also aware of the fact that presence of multicollinearity in the data set will make estimates of coefficients from the least squares fit imprecise and Statistically insignificant (Multivariate Calibrations test by Naes and Martens). If the primary aim is simply to predict the dependent variable (Y) using the X variables, multicollinearity might not be a critical issue. The model's predictions for Y could still be accurate, and the overall R^2 (or adjusted R^2_{adj}) will reflect how well the model fits the data for Y value prediction. However, multicollinearity becomes a significant concern when seeking to understand how individual X variables influence Y. Individual P-values for regression coefficients can be misleading. A high P-value might suggest an unimportant variable, even if it contributes to the overall prediction. The confidence intervals around the regression coefficients become very wide. These intervals may even include zero, making it difficult to determine if an increase in an X variable leads to an increase or decrease in Y. Due to the wide confidence intervals, removing or adding a data point can significantly change the coefficients and even reverse their signs.

Sometimes, multicollinearity can lead to seemingly paradoxical results. The overall model fit (indicated by a low overall P-value) might be good, yet individual X variables lack statistical significance in predicting Y. This occurs because highly correlated X variables provide redundant information. While neither variable may contribute significantly on its own, together they improve the model's fit. Removing them would significantly worsen the overall prediction. Therefore, multicollinearity can lead to a well-fitting model for prediction purposes, but hinder the interpretation of the individual X variables' effects on Y.

Test of Hypothesis about Full Regression Model

Hypothesis 1: [Test of significance encompassing all regression parameters]

Null hypothesis (H_0): The model fits the data/ The model is adequate

Alternative hypothesis (H_0): Not H_0

Or mathematically,

Null hypothesis (H_0): $\beta_1 = \beta_2 = \dots = \beta_{13} = 0$ [No single predictor showed significant contribution to the model]

Alternative hypothesis (H_0): : $\beta_j \neq 0$ for at least one j [At least one predictor showed significant contribution to the model]

Tests statistic: $F_{ratio} = \frac{MS_{Regression}}{MS_{Error}}$ [Global F-test]

Decision rule: Reject null hypothesis and accept alternative hypothesis at 0.05 significance level if **P – value** < 0.05, or else do not reject null hypothesis.

Hypothesis 2: [Test of significance encompassing individual regression coefficient]

Null hypothesis (H_0): $\beta_j = 0$ [Predictor x_j is not significant given that others are included in model]

Alternative hypothesis (H_0): : $\beta_j \neq 0$ [Predictor x_j is significant given that others are included in model]

Tests statistic: $t_{value} = \frac{\beta_j}{\sqrt{C_{jj}\sigma^2}}$ [Individual t-test]

C_{jj} = diagonal element of the covariance matrix corresponding to β_j

σ^2 = variance of β_j

Decision rule: Reject null hypothesis and accept alternative hypothesis at 0.05 significance level if **P – value** < 0.05, or else do not reject null hypothesis.

Results

The results of the descriptive statistics obtained for soil properties is presented in Table 1. Results obtained for the Pair-wise correlation of variables measured during field capacity experiment is presented in Table 2. Results of parameter estimates for the models generated for field capacity is presented in Table 3. Results of the Analysis of Variance (ANOVA) for the multiple regression models created for field capacity are presented in Table 4.

Table 1. Descriptive Statistics for Soil Properties

Soil Properties	Mean	Min	Max	Std dev	C.V
Sand (g/kg)	636.96	400	885	140.15	22.00
Silt (g/kg)	198.73	31	270	70.37	35.41
Clay (g/kg)	166.53	82	350	88.38	53.08
Bulk density (kg/m ³)	1402.36	1065	1698	140.19	10.00
Total porosity (m ³ /m ³)	0.471	0.359	0.598	0.053	11.25
OM (g/kg)	13.12	1.38	27.80	7.40	56.40
Field capacity (%)	44.05	32.26	71.43	11.89	26.99

Table 2. Pair-wise correlation results of variables measured during Field capacity experiment

	Sand	silt	Clay	Bulk density	Total porosity	Field capacity	OM
Sand	1						
Silt	-0.87029266*	1					
Clay	-0.90868682*	0.602503779*	1				
Bulk density	0.08398562	0.01706638	-0.162240647	1			
Total porosity	-0.08358332	-0.017237012	0.161766436	-0.99999666*	1		
Field capacity	-5.8922E-05	-0.114847322	0.079452573	-0.58174566*	0.581464586*	1	
OM	0.667549445*	-0.512282805*	-0.689291767*	-0.00388336	0.003886232	0.187994915	1

* Significant at 5% level when $r \geq 0.293955$

Table 3. Table of Parameter Estimates for Field Capacity Models

Model No.	P-value of Model	Model Multiple R-square value	Model Adjusted R-square value	Coefficients	Estimates	Std. Error	t value	P-value
1.	0.001367	0.4198	0.3282	(Intercept)	5.300e+03	1.115e+04	0.475	0.637
				Clay	-4.361e-02	1.031e-01	-0.423	0.675
				Sand	-8.055e-02	1.026e-01	-0.785	0.437
				Silt	-9.964e-02	1.073e-01	-0.929	0.359
				Bulk Density	-1.981e+00	4.218e+00	-0.470	0.641
				Total Porosity	-5.107e+03	1.113e+04	-0.459	0.649
				OM	4.729e-01	2.868e-01	1.649	0.107
2.	0.0003842	0.4707	0.3849	(Intercept)	7.092e+03	9.801e+03	0.724	0.474
				Clay	-4.141e-02	9.046e-02	-0.458	0.650
				Sand	-8.712e-02	9.009e-02	-0.967	0.340
				Silt	-1.255e-01	9.447e-02	-1.328	0.192
				Bulk Density	-2.653e+00	3.708e+00	-0.716	0.479
				Total Porosity	-6.891e+03	9.784e+03	-0.704	0.486
				OM	3.275e-01	2.551e-01	1.284	0.207
3.	0.0001429	0.5104	0.4288	(Intercept)	7.037e+03	9.356e+03	0.752	0.4569
				Clay	-2.221e-02	8.682e-02	-0.256	0.7995
				Sand	-8.267e-02	8.603e-02	-0.961	0.3430
				Silt	-1.292e-01	9.020e-02	-1.433	0.1605
				Bulk Density	-2.633e+00	3.539e+00	-0.744	0.4617
				Total Porosity	-6.848e+03	9.339e+03	-0.733	0.4682
				OM	4.390e-01	2.490e-01	1.763	0.0864
4.	1.856e-05	0.5021	0.4497	(Intercept)	153.787791	20.408264	7.536	4.69e-09 *
				Sand	-0.065790	0.022221	-2.961	0.005264 *
				Bulk Density	-0.037695	0.009059	-4.161	0.000175 *
				Silt	-0.113318	0.038384	-2.952	0.005384 *
				OM	0.487612	0.232312	2.099	0.042520 *

Table 4. ANOVA Table for Models developed for Field Capacity

Model No.	Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F-values	P-values
1.	Clay	1	39.3	39.27	0.4135	0.5241
	Sand	1	185.7	185.73	1.9557	0.1701
	Silt	1	134.7	134.75	1.4189	0.2410
	Bulk Density	1	1941.1	1941.09	20.4391	5.855e-05*
	Total Porosity	1	52.3	52.31	0.5508	0.4626
	OM	1	258.3	258.27	2.7195	0.1074
	Residuals	38	3608.8	94.97		
2.	Clay	1	115.54	115.54	1.5790	0.21678
	Sand	1	400.72	400.72	5.4761	0.02478 *
	Silt	1	193.82	193.82	2.6488	0.11212
	Bulk Density	1	1512.61	1512.61	20.6710	5.67e-05*
	Total Porosity	1	64.46	64.46	0.8808	0.35406
	OM	1	120.61	120.61	1.6482	0.20719
	Residuals	37	2707.49	73.18		
3.	Clay	1	154.44	154.44	2.3161	0.136775
	Sand	1	529.42	529.42	7.9395	0.007807 *
	Silt	1	224.58	224.58	3.3680	0.074748
	Bulk Density	1	1314.34	1314.34	19.7106	8.205e-05 *
	Total Porosity	1	72.79	72.79	1.0915	0.303099
	OM	1	207.30	207.30	3.1088	0.086356
	Residuals	36	2400.56	66.68		
4.	Sand	1	4.10	4.10	0.0638	0.80200
	Bulk Density	1	1748.85	1748.85	27.2203	6.722e-06 *
	Silt	1	426.02	426.02	6.6309	0.01404 *
	OM	1	283.05	283.05	4.4056	0.04252 *
	Residuals	38	2441.42	64.25		

Discussion

Statistical Analysis

Descriptive Statistics Analysis

The results obtained in Table 1 for the values of sand, silt and clay contents, bulk density, total porosity, OM and field capacity ranges from 400 to 885, 31 to 270, 82 to 50 g/kg, 1065 to 1698 kg/m³, 0.359 to 0.598 m³/m³, 1.38 to 27.80 g/kg and 32.26 to 71.43%, respectively.

Pair-wise correlation

Sand had negative correlation with silt ($r = -0.870^*$) and clay ($r = -0.909^*$) (Table 2). As sand increases, silt and clay will decrease. Sand was positively correlated with OM ($r = 0.668^*$) as sand increases, OM will increase. Silt was positively correlated with clay ($r = 0.603^*$) and inversely correlated with OM ($r = -0.512^*$) this shows that silt affects OM negatively and as silt increases, clay will also increase. Clay had negative correlation with OM ($r = -0.689^*$) clay affects OM negatively. Bulk density had negative correlation with total porosity ($r = -0.999^*$) and field capacity ($r = -0.582^*$) as bulk density increases total porosity and field capacity decreases. Total porosity was positively correlated with field capacity ($r = 0.581^*$) as total porosity increases, field capacity will increase.

Model Development

Four models with p-values < 0.05 were created for field capacity with the corresponding R² adjusted values of 0.3282, 0.3849, 0.4288 and 0.4497 for models 1, 2, 3 and 4 as shown in Table 7. Model 4 of field capacity was selected as the best predictive model due to having the highest R² adjusted value of 0.4497. This implies that the model fits the field capacity data with the four predictors included after removal of observations with potential outliers and non-significant predictors clay and total Porosity so as to determine the model's prediction accuracy. The model justifies approximately 45% of the variation in mean squared errors of field capacity with sand, bulk density, silt and organic matter being statistically significant contributors to the model.

Examining the significance of each predictor variable in Table 4 for model 4 of field capacity, the results show that we can reject the null hypothesis for bulk density, silt and OM with p-values of 6.722e-06, 0.01404 and 0.04252, respectively. The simple interpretation of this is that each variable is statistically significant within the model when considered alongside the other included variables. This suggests they contribute meaningfully to the model's explanatory power in combination. It does also mean they cannot be excluded. The expression of model 4 as given in Table 3 is expressed in equation (10) as:

$$\hat{Y} = 153.787791 - 0.065790 * \text{Sand} - 0.113318 * \text{Silt} - 0.037695 * \text{Bulk Density} + 0.487612 * \text{Organic Matter} \quad (10)$$

For model 4 of field capacity, the residuals are now normal and there are no potential outliers as shown in Figure 1. In fact, the Cook's distance plot now confirms this by having all the Cook's distances for all the predictors less than 1 as shown in Figure 1. The residuals plot and normal quantile-quantile plots presented in Figure 1 also support this. Normality of the residuals is further confirmed by the histogram presented in Figure 2.

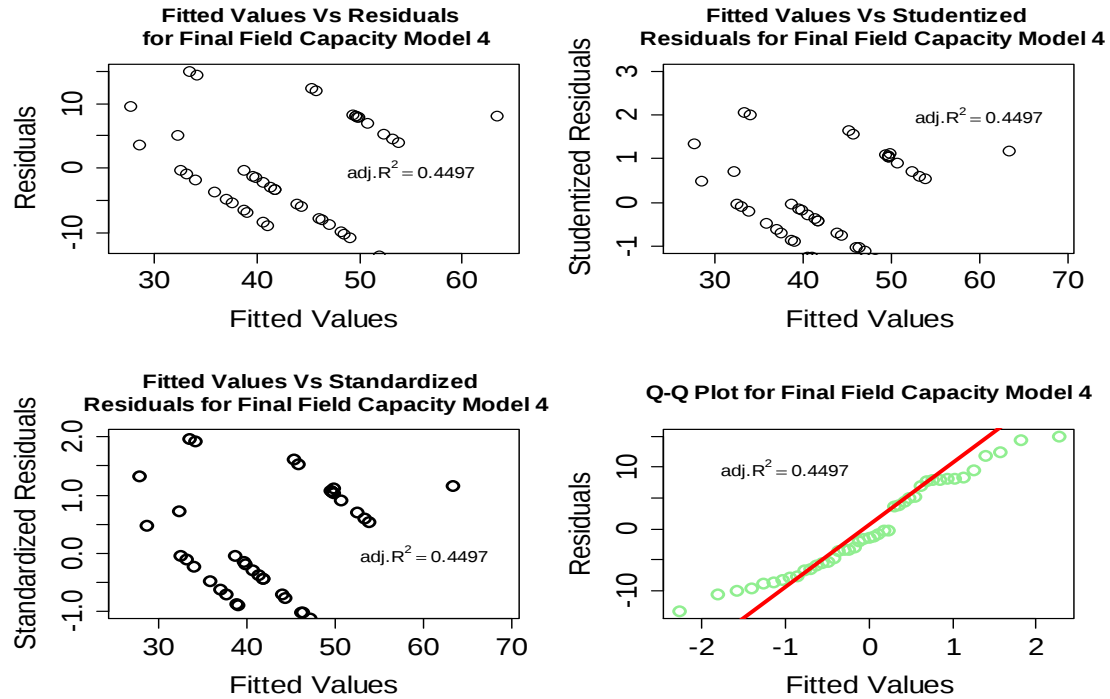


Fig. 1. Diagnostic Plots for Model 4

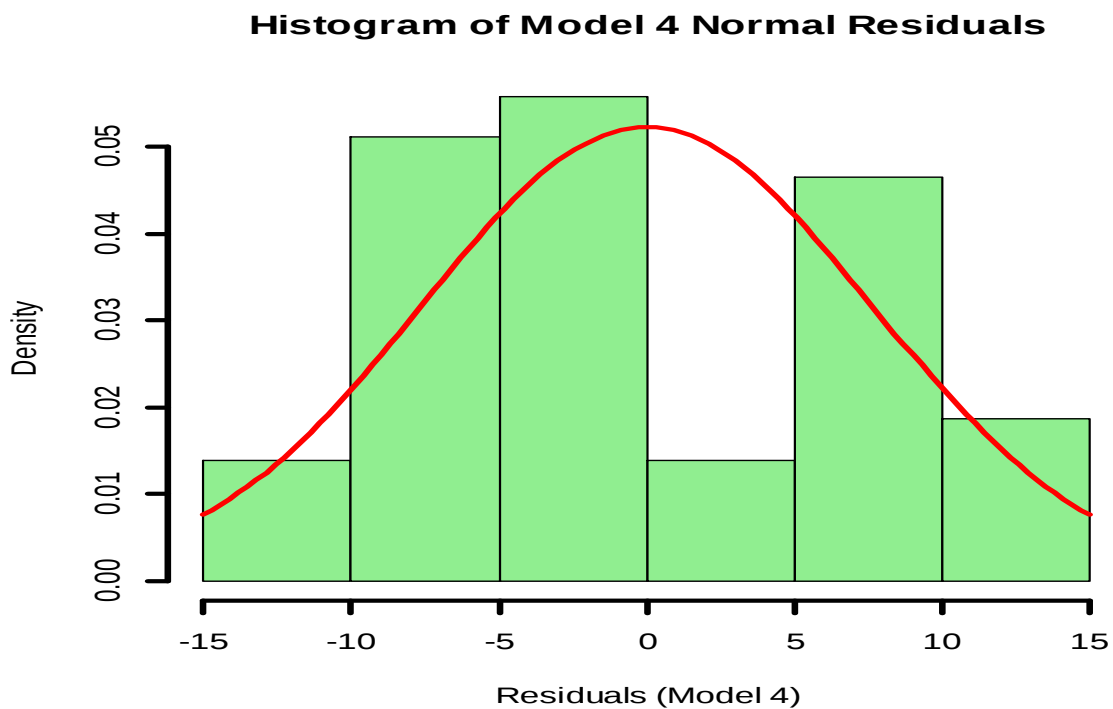


Fig. 2. Histogram of Model 4 Normal Residuals

The model equation generated for model 4 was used in predicting the field capacity values shown in Table 5. Table 5 presents observed, predicted and residuals of the prediction. The values obtained for observed and predicted field capacity as presented in Table 5 were analyzed for extent of relationship and presented a correlation coefficient of 0.7086. Based on the guideline outlined at <http://www.westgard.com/lesson42.htm> for assessing correlation coefficients, it is observed that when r falls within the range of 0.90 and 1.00, 0.70 and 0.89, 0.50 and 0.69, 0.30 to 0.49, and 0.00 to 0.29 are said to show very high, high, moderate, low, and little if any correlation, respectively. It indicates that field capacity predictions of model 4 of field capacity have high correlation relationship with the observed field capacity values.

The graph of observed and predicted field capacity values is presented in Figure 3. This shows the trend of observed and predicted values of field capacity.

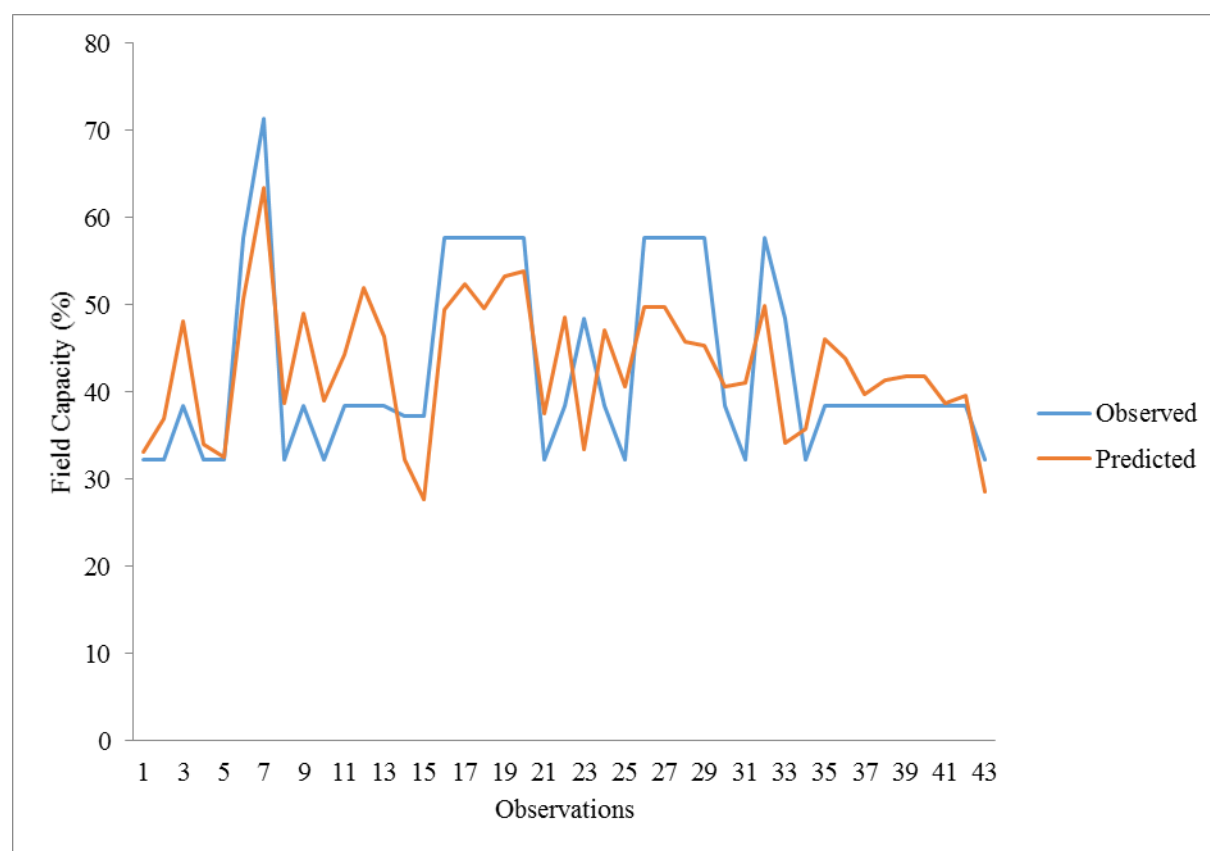


Fig. 3. Graph of Observed versus Predicted Field Capacity

Table 5. *Summary of Model 4 Prediction of Field Capacity*

Observations	Observed Y (%)	Predicted Y (%)	Residuals ($Y - \bar{Y}$)
1	32.26	33.07635	-0.81635
2	32.26	37.02047	-4.76047
3	38.46	48.16551	-9.70551
4	32.26	33.96041	-1.70041
5	32.26	32.50082	-0.24082
6	57.69	50.70623	6.983774
7	71.43	63.37098	8.059022
8	32.26	38.74145	-6.48145
9	38.46	49.08697	-10.627
10	32.26	38.98002	-6.72002
11	38.46	44.33006	-5.87006
12	38.46	51.89833	-13.4383
13	38.46	46.34247	-7.88247
14	37.31	32.24192	5.068075
15	37.31	27.7532	9.556797
16	57.69	49.4147	8.275303
17	57.69	52.42	5.269999
18	57.69	49.63758	8.052422
19	57.69	53.22095	4.469047
20	57.69	53.8081	3.881896
21	32.26	37.5815	-5.3215
22	38.46	48.55325	-10.0933
23	48.39	33.43684	14.95316
24	38.46	47.08808	-8.62808
25	32.26	40.62179	-8.36179
26	57.69	49.80101	7.888989
27	57.69	49.68176	8.008239
28	57.69	45.74357	11.94643
29	57.69	45.29467	12.39533
30	38.46	40.567	-2.107
31	32.26	41.06191	-8.80191
33	57.69	49.85784	7.832161
34	48.39	34.08673	14.30327
35	32.26	35.84598	-3.58598
36	38.46	46.11329	-7.65329
37	38.46	43.909	-5.449
38	38.46	39.81466	-1.35466
39	38.46	41.38441	-2.92441
40	38.46	41.76351	-3.30351
41	38.46	41.77301	-3.31301
42	38.46	38.70256	-0.24256
43	38.46	39.62808	-1.16808
44	32.26	28.61995	3.640048

Note: Observations 32 and 45 are not included because they contain potential outliers

Conclusion

In the experiment carried out at the University of Ilorin Teaching and Research Farm for developing a model for predicting field capacity of the soil, a total of four distinct models were created. Model four of field capacity was chosen as the best model, having the highest R^2 adjusted value of 0.4494. Sand, silt, bulk density and OM was found a fitting option to ascertain soil moisture at field capacity.

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Study of Basaltic Soils Along the Toposequence of Aya River in Ogoja, Cross River State, Nigeria



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Abstract

An investigation was carried out on selected properties of basaltic soils along the toposequence of Aya river in Ogoja Cross river state. The soils are deep and occur on a gentle and undulating landscape with a gradient of <4%. Three profile pits were dug in each of the mapping units identified as crest, mid-slope and valley bottom. Each Pedon had four distinct genetic horizons (Ap, AB, Bt1 and Bt2). The dominant matrix for the Ap horizon was dark brown (7.5YR3/4), brown (7.5YR6/4) and yellowish brown (10YR6/8) for pedons I, II and III respectively. The particle size distribution data indicates the preponderance of sand fraction while the percentage sand mean values are 82.45 %, 81.45 % , 85.78 % and 81.0 % for pedons III, II and I respectively. The soils reaction pH_{H2O} is assessed as strongly acidic ranging from 5.25-5.75. The exchangeable Ca²⁺, Mg²⁺ and K⁺ are in low concentrations but are within the threshold of critical limits. Organic carbon and total nitrogen and available P were generally low (N: 1.7-1.1 g/kg; OC:7.3-5.1 g/kg and P:18.25- 12.60 g/kg). The Organic C/N ranged from 3 – 7 and Ca/Mg had mean of 1.40, 1.36 and 1.31 in pedons I, II, and III respectively. The base saturation (%BS) was high to very high (64.70-79.26 %) while effective cation exchange capacity was generally low (2.03 cmol/kg, 2.29 cmol/kg, and 1.93 cmol/kg for pedons I, II, and III respectively). The soil on the toposequence of Aya river showed evidence of oxic properties with absence of weatherable minerals in the sub stratum. The soil suitability class were moderately suitable with limitations in pH and low soil organic matter content. The soils were classified as Isohyperthermic ustalfs which corresponded to Arenic Luvisols (pedons 1 and 2) with fluvic characteristics in pedon 3 (WRB, 2006). Soil quality of the studied soils is low due to the established unfavourable fertility indicators; hence soil conservation and use of integrated soil fertility management- organic sources (compost manure), inorganic sources (NPK fertilizers) and crop rotation as well as conservational tillage is recommended.

Keywords: basaltic materials, toposequence, morphology, classification, suitability

Introduction

Soils formed on basaltic parent materials are usually rich in ferromagnesian minerals mainly plagioclase feldspar (which are rich in Ca and/or Na- $\text{CaAl}_2\text{Si}_2\text{O}_4$ or $\text{NaAl}_3\text{Si}_2\text{O}_8$) and pyroxene [$(\text{Mg}, \text{Fe})_2\text{SiO}_4$] (Esu et al., 2015) and (Ojo-Atere et al., 2011). Esu et al., (2015) in their investigation in the morphological, physicochemical and mineralogical properties of soils developed from basalt at not too far away Ikom, they established that 77.7% of the mineralogy is composed of kaonilite, 10.75% is Fe bearing minerals (goethite and hematite) and they concluded that these soils are dominated by highly resistant minerals, a sign of soil in an oxic state of weathering where leaching, eluviation-illuviation, laterization and faunal pedoturbation are common features (Esu et al., 2015 and Eshett, 1987). In many tropical soils, where excessive rainfall and leaching of the bases results in the acidification of the soils through Fe- Al saturation in the exchange site while Nsor and Akamigbo (2015), also observed the problem of plinthization in the soils of central cross river state.

Topography depends on the configuration of the system in the of elevation, slope and landscape expositions. Differences in topography can cause wide variations in soils within the confines of a single field. Topography determines the local distribution or disposal of the precipitation and determines the extent to which water tables influence soil genesis (Foth, 1990). Topography hastens or delays the work of climatic factors in pedogenesis with respect to soil horizon development (Brady and Weil, 1999). Toposequence is used interchangeably with catena by many soil scientists, and catena concepts have emanated as slope- soil evolutionary process (Esu et al., 2008). The soils differ as a result of erosion, transportation and deposition of surficial materials as well as leaching, translocation and deposition of chemical and particulate constituents in the soil. These processes result in morphological changes associated with soil colour and horizonation as a result of hydrology related to topographic position (Juo and Moorman, 1980). Soil colour is one of the important basic properties which help in identifying the kinds of soils and recognize the successions of soil horizons or layer in the soil profile and it gives the physical structure of the soil some intrinsic imprint that are related to topography. It has been used for soil identification and qualitative measurements of soil properties and serves as a useful tool in field studies (Noshadi et al., 2013). While Wakene (2003), stated soil colour is function of pH, redox reaction, and organic matter. A change in soil colour from adjacent soil also indicates a difference in the soil mineral origin or soil development, geologic origin and degree of weathering of the soil material and leaching or accumulation of chemical compounds such as iron, which may greatly influence soil quality (Fisher and Binkley, 2000). Though not all soils are strongly correlated with terrain attributed, much less can be linked to them in a straightforward functional way (Sobieraj et al., 2002), this is even more complex within agricultural field where different types of land use types are practiced. Landscape position influences rainfall, drainage and erosion, water velocity on a slope affects deposition of materials in suspension, the largest sized particles like sand are the first to drop out of suspension, fine clay size particles can be carried further away from the base of the slope before they are deposited. Hill slope orientation also affects the microclimate of a place, inclined surface facing into the sun tend to be warmer and drier than flatter surface facing away from the sun (Atofarati et al, 2012). Soils developed on a toposequence have been found to be suitable in the production of crops such as tree crop (*Theobroma cacao* and

Gmelina aborarea), food crops (yam, cassava and maize) and vegetables (tomato, fluted pumpkin and garden egg etc). These were reported by Eshett (1987) for basaltic soils on the toposequence at Ikom in Northern Cross river state, Nigeria. Soil in the tropics are extremely diverse, they ranged from young fertile to senile soils. The objectives of this study were to characterise and classify the basaltic soil along the toposequence of Aya river in Ogoja Cross River state and study its suitability classification for selected crops.

Materials and Methods

Site Description

The study area was along the toposequence of Aya River in Ogoja Local Government Area of Cross River State. It lies between latitude 6°41.38'N and longitude 8°58.03'E. The area has distinct rainy (March to October) and dry seasons. The mean annual rainfall in the study area ranges from 1728 - 2200 mm with double maxima in the months of July and September. Mean annual temperature varies from 22.4° to 32.5°C while the mean annual relative humidity varied from 74 to 79%. The climate of the area is sub-humid tropical, and its vegetation is forest-grassland-savanna. The soils are generally derived from the basaltic and alluvium of either false-bedded sandstone or the upper coal measure (Asadu, 1990) with gentle undulating plains with scattered rock outcrops. The hydrology is governed by Aya River (it raises from Obudu plateau) which is a major tributary of Cross River. The soils are well drained with few poorly drained soils (loamy sand to sandy clay) which are used for paddy rice and sugarcane cultivation. Its vegetation is characterized as forest- grassland-savannah (transitional vegetation type). Agriculture is the major socioeconomic activities in the area with cottage industries in fishing and agricultural related enterprises. The major farm produce is yam (*Dioscorea* spp), plantain (*Musa paradisiaca*), cassava (*Manihot esculenta*), rice (*Oryza sativa*), ground nut, maize, soybean, bambara nut (*Vigna subterranean*) and vegetables (water leaf and fluted pumpkin- *Telfairia occidentalis*). The area is rich in forest resources but with the rate of current deforestation amidst uncontrolled access. Oil palm (*Elaeis guineensis*) and cocoa (*Theobroma cacao*) are common but value addition to oil palm fruits is also a major cottage industry alongside cassava processing.

Field Work

Three mapping units were identified and classified based on physiographic position along the toposequence and associated landuse. A stratified random sampling technique was adopted in the study. The profile pits were dug at upper, mid-slope and lower part of the slope. A total of three profile pits was sunk and described following the guidelines of FAO, (2006). Soil samples were taken for routine physical and chemical analysis.

Laboratory Analysis

The pH was determined by glass electrode pH meter both in 1:2.5 soil/ liquid suspension of water and KCl (Henderson et al., 1993). Particle size analysis was by hydrometer method (Gee and Or, 2002). Organic carbon was determined by wet dichromate method by Udo et al., (2009). Total nitrogen was determined by micro-Kjeldahl digestion method as modified by Udo et al., (2009). Extraction of available phosphorus was done using Bray 1 method. Exchangeable cations (K^+ , Ca , Mg^{2+} , and Na^+) were extracted by neutral

normal ammonium acetate, K^+ and Na^+ in the extraction were determined by flame photometer (Udo et al., 2009) while Ca^{2+} and Mg^{2+} were by atomic absorption spectrophotometer. Cation exchange capacity was by summation method. Exchangeable acidity was determined in 1NKCl extracting solution with 0.5N NaOH using phenolphthalein indicator by titration method of Mclean as described by Udo et al., (2009). Bulk density was measured by core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓ_p) values with assumed particle density (ℓ_s) 2.65 g cm^{-3} as follows, Porosity (P_o) = $100 - (\ell_p/\ell_s) \times 100/1$

Statistical analysis was performed using Genstat statistical package for the analysis of variance and treatment mean compared using least significant difference at 5% level of probability.

Table 1. Location Coordinates and Elevation

Position	Profile code	Elevation (M.A.S.L)	North-East coordinates
Lower	III	110	6°39'27.9"N, 8°59'23.0"E
Mid-slope	II	108	6°39'27.3"N, 8°59'21.8"E
Upper (Crest)	I	119	6°39'27.3"N, 8°59'20.4"E

Results and Discussion

Morphological properties of the studied soils are shown in table 2, the physiographic mapping units have different colour matrix range, and all the horizons are deep and well drained characterized by loose top soil. The peds are generally arranged in weak to moderate granular and sub angular blocky, clear wavy horizon boundaries and soils have fine and medium roots and pronounced faunal activities in the epipedons. The soil at the slope appears to be shallow with a depth of 92 cm while the depth at both the midslope and valley bottom are well above 110 cm, this was in agreement with the findings of Ofem and Esu (2015). The soil colour varies from the crest to the valley bottom, the crest is dominated by brownish yellow (10YR6/8) at 0-25 cm and strong brown (7.5YR5/8) at depth of 25-47cm, reddish yellow (7.5YR5/8) at 47-76 cm and 5YR7/8 at 76-92 cm. The mid-slope is dominated by brownish colour 7.5YR4/4 at 0-17cm, dark yellowish brown (10YR4/6) at 17-39cm, yellowish red (5YR6/6) at 39-100cm. the soils at the valley bottom had dark brown (7.5YR3/4) at 0-20cm, strong brown (7.5YR5/8) at the sub surface profiles, the variation in colour matrix of the soils is a reflection of the sequence of drainage condition and physiographic positions and this conformed with the works of Nuga et al., (2006) and Akamigbo and Asadu (1986). The presence of many fine pores, many fine roots and fauna activities in Ap horizon of the pedons are indicative of the desirable effect of soil organic matter which enhances aggregate stability (Daniel, et al., 2000). Termites and earthworms were observed as agents of micro-faunaturbation in the study areas.

Table 2. *Morphological Properties of Soils Along the Toposequence of Aya River*

Depth (cm)	Horizon	Colour	Text Ure	Structure	Horizon bound	Consist.	Veg.	Root presence
Crest Pedon 1								
0-25	Ap	Yellowish brown (10YR6/8)	LS	Gr	SC	NSNP		Many(vf-f)
25-47	AB	Strong brown (7.5YR5/8)	LS	Gr	SC	NSNP		Common(vf-f)
47-76	Bt1	Reddish yellow (7.5YR6/6)	SL	Gr	SC	NSNP	SR	Few(f)
76-92	Bt2	Reddish yellow (5YR7/8)	SL	Gr	SC	FRSST		Very few(F)
Midslope Pedon 2								
0-17	Ap	Brown (7.5YR6/4)	LS	Gr	CW	Crumby		Many(vf-f)
17-39	AB	Dark yellowish brown(10YR6/4)	LS	SAB	CW	Friable		Common(vf-f)
39-74	BT1	Yellowish Red (5YR6/6)	SCL	SAB	CW	Extremely firm	SR	Few(f)
74-135	BT2	Yellowish (5YR7/8)	Red SCL	SAB	CW	Extremely firm		Very few(F)
Valley Pedon3								
0-20	Ap	Dark brown (7.5YR3/4)	LS	Gr	CS	Friable		Many(vf-f)
20-44	AB	Strong brown (7.5YR5/8)	LS	Gr	CS	Friable	SR	common(vf-c)
44-72	Bt1	Strong brown (7.5YR4/6)	S	Gr	CS	Firm and sticky		Few(f)
72-110	Bt2	Strong brown (7.5YR5/6)	SL	Gr	CS	Very firm and sticky		Very Few(f)

Colour: YR = reddish yellow, Structure: Gr= granular, SAB = subangular blocky, Consistence: NSNP= non sticky non plastic. FRSST = friable slighty sticky, Roots: C= coarse, vf = very fine, vf = very few, f= few, f=fine, vegetation: SR= secondary regrowth

The physical properties of the studied soils are shown in table 3. The particle size distribution data indicates the preponderance of sand in all the pedons in the study area; this suggests they have quartzite in its geology. The mean values of sand are 82.45 % (pedon III), 81.45 % (pedon II), 85.78 % and 81.0 % (pedon I). This is in contrast with the several authors who reported the dominance of clay in the textural class. The difference in the textural class may be due to intense and prolonged precipitations in the study area.

The silt content showed no regular pattern in pedons I and III but without a fluctuation the profile in pedon II. Clay content was generally higher than silt content in all of the studied pedons. The highest clay content was established in pedon II (17.15%). This trend is a common physical feature with soils in this zone and this is due to weathering of silt fraction into clay. The silt clay ratio (SCR) in the studied profile showed mean values of <1, which indicates of reserve of weatherable minerals in the substratum as typical of kandiusalfs (USDA, 2015). The SCR is an index for gauging extent of weathering in soils (Oleghe and Chokor, 2015).

The textural classes range from loamy sand in the top soil (Ap horizon) and sandy loam in the subsoil. Pedon II has loamy sand in (Ap horizon) and sandy clay loam (subsoil), pedon III had loamy sand (Ap horizon) and sandy loam (subsoil). The mean values of bulk density were 1.24 g/cm⁻³, 1.17 g/cm⁻³, 1.27 g/cm⁻³ for pedons I, II and III respectively. The bulk density decreased with profile depth though values obtained are within the range for good rooting crops (Soil Survey Staff, 2006 and Ladon, 1991).

The porosity values range from 52 % - 56 %. These porosity values indicate good soil-air conditions. This meets with the study of Chude et al., (2011); which noted that soil physical properties are dominant factors affecting the usage of soils. This is because the success or failure of agricultural venture (crop wise) is often hinges on the physical properties of the soil and physical properties are more difficult to change than chemical properties (Okolo et al., 2015). Several authors (Sanchez, 2019) pointed out that the soil texture is less susceptible to change

Table 3. *Physical Properties of Soils Along the Toposequence of Aya River*

Horizon	Depth (cm)	Sand (%)	Clay (%)	Silt (%)	SCR	TC	BD g/cm ³	Po	MC %
Crest (pedon I)									
Ap	0-22	86.2	11.4	2.4	0.21	LS	1.27	52	8.31
AB	25-47	85.2	13.4	1.4	0.1	LS	1.42	46	8.48
Bt1	47- 76	82.2	14.4	3.4	0.24	SL	1.33	50	9.44
Bt2g	76- 92	76.2	18.4	5.4	0.24	SL	1.05	60	14.9
Mean		82.45	14.4	3.15	0.21		1.27	52	10.28
SD±		4.5	2.94	1.71	0.08		0.08	3.12	3.123
CV		5.46	20.42	54.29	38.1		12.6	30.35	30.35
Midslope (pedon II)									
Ap	0-17	89.2	9.4	1.4	0.15	LS	1.19	55	8.03
AB	17-39	85.2	13.4	1.4	0.1	LS	1.29	51	6.32
Bt1	39-74	78.2	20.4	1.4	0.07	SL	1.11	58	9.16
Bt2g	74- 135	73.2	25.4	1.4	0.06	SCL	1.07	60	11.7
Mean		81.45	17.15	1.4	0		1.17	56	8.8
SD±		7.14	7.14	0	0.1		0.1	2.26	2.26
CV		8.77	41.63	0	4.45-7.55		48.55	25.68	25.68
Valley bottom (pedon III)									
Ap	0-20	86.8	7.3	5.9	0.81	LS	1.28	52	8.9
AB	20-44	89.8	8.3	1.9	0.23	LS	1.16	56	20.1
Bt1	44- 72	91.8	7.9	0.3	0.04	S	1.25	53	6.62
Bt2g	72- 110	74.7	13.1	12.2	0.93	SL	1.28	52	5.92
Mean		85.78	9.15	5.06	0.5		1.24	53	10.39
SD±		7.66	2.67	5.3	0.43		0.06	6.6	6.6
CV		8.93	29.18	104.74	86		4.84	63.52	63.52
LSD(5%)		10.92	30.2	39.16	16.5		0.01	17.6	59

SCR= silt/ clay ratio, TC= textural class, BD g/cm³, Po= total porosity, MC = moisture content

The chemical properties of the studied soil are as presented in table 4. The pH had mean values of 5.50, 5.46 and 5.64 for pedons I, II and III respectively, the soil reaction generally ranges from strongly acidic in the topsoil to moderately acidic in the subsoil (acidity decreased with profile depth). The acidity may be due to leaching caused by precipitations and urea fertilizer application (many of the farmers are found to apply urea fertilizers in crop production). This indicates that the soils are strongly acidic and shows that there are significant exchangeable Al^{3+} and H^+ hence the entire soil will have net negative charges on soil colloids and this will engender cation adsorption on the soil exchange complex (Kolay, 2002).

According to Osodeke, (2017) such acidic cause fixing of nutrients such as phosphorous, potassium, and sulphur hence making them unavailable for plant uptake. The exchangeable Ca^{2+} , Mg^{2+} and K^+ are in low concentrations but are within the threshold of critical limits for deficiencies and likely in response to fertilization (Adisa et al., 2016 and Haby et al., 1990). The mean value for exchangeable Ca^{2+} was 0.86 cmol/kg, 0.78cmol/kg and 0.82 cmol/kg in pedons I, II and III respectively. The concentration of exch. Mg^{2+} is close to that of exch. Ca^{2+} with mean values of 0.61 cmol/kg, 0.57 cmol/kg and 0.63 cmol/kg in pedons I, II and III respectively. Exchangeable Mg^{2+} below 0.28 cmol/kg would manifest as deficiency in maize (FMANR, 1990).

Organic carbon and total nitrogen and available P were generally rated low to moderate (N: 1.7-1.1 g/kg; OC: 7.3-5.1 g/kg and P: 18.25- 12.60 g/kg). The obtained value of TN, OC and available P obtained were higher than those reported by Ofem and Esu (2015). These variations may be due to climatic factors and agronomy practices.

The soil would require higher amount of N and P fertilizers to maintain their adequate supply. The application of gypsum is required to increase the soil pH, release the fixed phosphorous and boost Ca and Mg in the soil (Osodeke, 2017, Esu et al., 2015). The mean values of exch. K^+ were assessed as very low 0.01 cmol/kg in all of the studied pedons. This is very critical for crop development as K^+ is macro element in plant nutrition. Therefore, K^+ in the profile is inadequate for crop utilization (Imadojemu et al, 2017). The org. C/N ratio and Ca/Mg ratio were range from very low to low.

The org. C/N is important for determining mineralization and immobilization of nitrogen, the C/N ranged from 3.15 – 6.64 which is below 25 favours mineralization set by Paul and Clark (1989). The established Ca/Mg ratio of <5.1 indicates low activity clay (Brady and Weil, 2014). The Ca/Mg ratio had mean values of 1.40, 1.36 and 1.31 in pedons I, II, and III respectively. The percentage base saturation (%BS) was high to very high (64.70-79.26 %), a similar result was reported by Ofem and Esu (2015).

The effective cation exchange capacity was assessed as low, the highest mean value was obtained in pedon II (2.29 cmol/kg). This means that the soil requires integrated soil fertility management (organic composting), inorganic (N.P.K fertilizers) and conservation agriculture (crop rotation, sub soil tilling etc).

Table 4. Chemical Properties of Soils along the Toposequence of Aya River

Horizon	Depth (cm)	pH H ₂ O ^(1:2.5)	% Org. Carbon	%TN	C/N	Av. P (ppmP/g)	TE A cmol/kg	Ca cmol/kg	Mg cmol/kg	Na cmol/kg	K cmol/kg	TEB cmol/kg	ECEC cmol/kg	%BS	Ca/Mg
Valley Bottom (pedon III)															
Ap	0-20	5.35	0.79	0.15	5.27	14.07	0.4	0.84	0.6	0.05	0.01	1.48	1.88	79	1.4
AB	20-44	5.55	0.48	0.15	3.2	14.42	0.4	0.84	0.6	0.05	0.01	1.48	1.88	79	1.4
Bt1	44-72	5.65	0.39	0.18	2.17	25	0.2	0.88	0.62	0.05	0.01	1.56	1.76	86	1.42
Bt2g	72-110	5.45	0.39	0.2	1.95	12	1	0.88	0.63	0.05	0.02	1.6	2.6	62	1.4
Mean		5.5	0.51	0.17	3.15	16.36	0.5	0.86	0.61	0.05	0.01	1.53	2.03	77	1.4
CV		2.36	37.25	11.76	48.25	35.76	70	2.33	3.23	16.67	1	39.22	18.72	14.64	6.23
Midslope (pedon II)															
Ap	0-17	5.6	0.81	0.09	9	15.83	0.35	0.76	0.56	0.05	0.01	1.38	1.73	80	1.36
AB	17-39	5.7	0.64	0.1	6.4	28.5	0.4	0.77	0.57	0.04	0.01	1.39	1.79	78	1.25
Bt1	39-74	5.25	0.57	0.13	4.38	21	1.2	0.79	0.58	0.05	0.01	1.43	2.63	54.4	1.36
Bt2g	74-135	5.3	0.71	0.13	5.46	18	1.6	0.79	0.58	0.04	0.01	1.42	3.02	63	1.36
Mean		5.46	0.68	0.11	6.31	18.25	0.89	0.78	0.57	0.05	0.01	1.41	2.29	77	1.36
CV		4.03	14.71	18.18	31.22	26.7	68.54	2.56	1.75	20	0	2.13	27.95	24.66	5.21
Crest (pedon I)															
Ap	0-22	5.45	0.81	0.1	8.1	12.31	0.3	0.82	0.61	0.07	0.02	1.52	1.82	84	1.34
AB	25-47	5.7	0.73	0.1	7.3	16.61	0.2	0.82	0.61	0.05	0.01	1.49	1.69	88	1.34
Bt1	47-76	5.65	0.71	0.12	5.92	7.74	0.5	0.82	0.64	0.05	0.01	1.52	2.02	75.25	1.28
Bt2g	76-92	5.75	0.63	0.12	5.25	13.72	0.65	0.82	0.64	0.05	0.01	1.52	2.17	70	1.28
Mean		5.64	0.73	0.11	6.64	12.6	0.41	0.82	0.63	0.06	0.01	1.51	1.93	79	1.31
CV		2.3	9.72	9.09	19.43	22.6	48.78	0	3.17	166.67	1	1.32	10.88	10.27	2.21
LSD(5%)		0.03	0.02	0	4.55	35.58	0.19	0	0	0	0	0.01	0.2	171.07	0

TN= Total nitrogen, C/N= carbon nitrogen ratio, Av, available phosphorous, TE total exch. Basea, ECEC= effective cation exch. Capacity, BS= base saturation

Correlation Matrix

The correlation matrixes are presented in table 5. There was a negative but highly significant correlation between sand and clay (-0.85**) while %BS and ECEC was also negative but highly significant correlation (-0.97**). The positive and highly significant correlations are the silt and clay, clay and ECEC, TN and OC.

Table 5. *Correlation matrix of selected physical and chemical Properties of the soils along the Toposequence of Aya River*

	Sand	Silt	Clay	SCR	pH	OC	TN	AvP	TEB	ECEC	BS
Sand	1										
Silt	-0.48	1									
Clay	-0.85**	-0.05	1								
SCR	-0.22	0.92**	-0.29	1							
pH(water)	-0.35	-0.13	-0.32	-0.25	1						
Oc	0.08	-0.28	0.08	-0.14	-0.06	1					
TN	-0.14	0.56	-0.18	0.56	-0.27	-0.8**	1				
AvP	0.19	-0.44	0.05	-0.42	0.01	-0.31	0.03	1			
TEB	-0.09	0.58*	-0.24	0.49	0.14	-0.51	0.67*	-0.42	1		
ECEC	-0.88**	0.31	0.81**	0.13	-0.65*	-0.23	0.33	-0.02	0.01	1	
BS	0.86**	-0.26	-0.82**	-0.09	0.64*	0.13	-0.19	-0.04	0.19	-0.97**	1

* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01

Soil Classification

The soils of the study area were classified using USDA Soil Taxonomy system (2015), and correlated with World Reference Base (2006). In classifying these soils, the criteria considered were nature of the epipedon, the types of diagnostic master horizon, the clay content, the organic matter content, the percentage base saturation, the presence, or absence of concretions (plinthitic features), the soil moisture, temperature regimes, diagnostic horizons and soils colour. The soils tends to have more bright hues (reddish brown) due to good aeration, these pedons was classified as in the order as Alfisols because of the presence of Bt horizon, high percentage base saturation and the absence of lamellae, suborder as ustalfs owing to the Ustic moisture regime, great group as Argillic typic ustalfs as the most subsoil horizons were argillic along with high OC contents as well as the high %BS while the preponderance of sand showed psammentic (USDA) correlates to Arenic (WRB). The subgroup was classified Eutric arenic Haplustalfs. The family was classified coarse sandy clay loam, Isohyperthermic, ustalfs and classified as Ogoja sandy clay loam series. This corresponds to Arenic Luvisols (pedons 1 and 2) with fluvic characteristics in pedon 3 (WRB, 2006).

Conclusion

Basaltic soils are rich in intermediate plagioclase feldspar which means they have reserve of weatherable minerals. The physical and chemical limitations of tropical Alfisols can be ameliorated by applying both conservational and good tillage practices. The soil texture was dominated by sand (85.78 %) followed by clay (17.15%), define texture as loamy sand. Soil reaction ranges from strongly acidic in the topsoil to moderately acidic in the

subsoil. The soil pH differ among the different pedons on the toposequence with mean values of 5.50 (Pedon I), 5.46 (Pedon II) and 5.64 (Pedon III). The soils had low BS (%). The total N was also low in concentrations. Available P was in medium concentrations and exch. K^+ and the Na^+ was assessed as very low concentrations and do not pose a threat to soil salinization. Most prominent problems to these soils are high temperature and precipitation. The soil quality and fertility indicators are generally low for these soils; hence soil conservation and use of integrated soil fertility management- organic sources (compost manure), liming, inorganic sources (NPK fertilizers) and crop rotation as well as conservational tillage is recommended. The soils were classified as moderately suitable with limitations in pH and low soil organic matter content.

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